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ABSTRACT

This manual for sewage treatment plant operators was prepared by a committee of operators, educators, and engineers for use as a reference text and handbook and to serve as a training manual for short course and certification programs. Sewage treatment plant operators have a responsibility in water quality control; they are the principal actors in implementing state and federal stream standards. Treatment as defined in this manual means disposal of wastes carried in a sewage system in a way that does not create a nuisance, interfere with aquatic life, or hurt the water or the environment. The manual includes chapters on treatment plant operation, collection of sewage, sewer maintenance, characteristics of wastes and their treatment, treatment and disposal component operation, sampling and testing, and mathematical and other fundamental information needed in the work. (MF)

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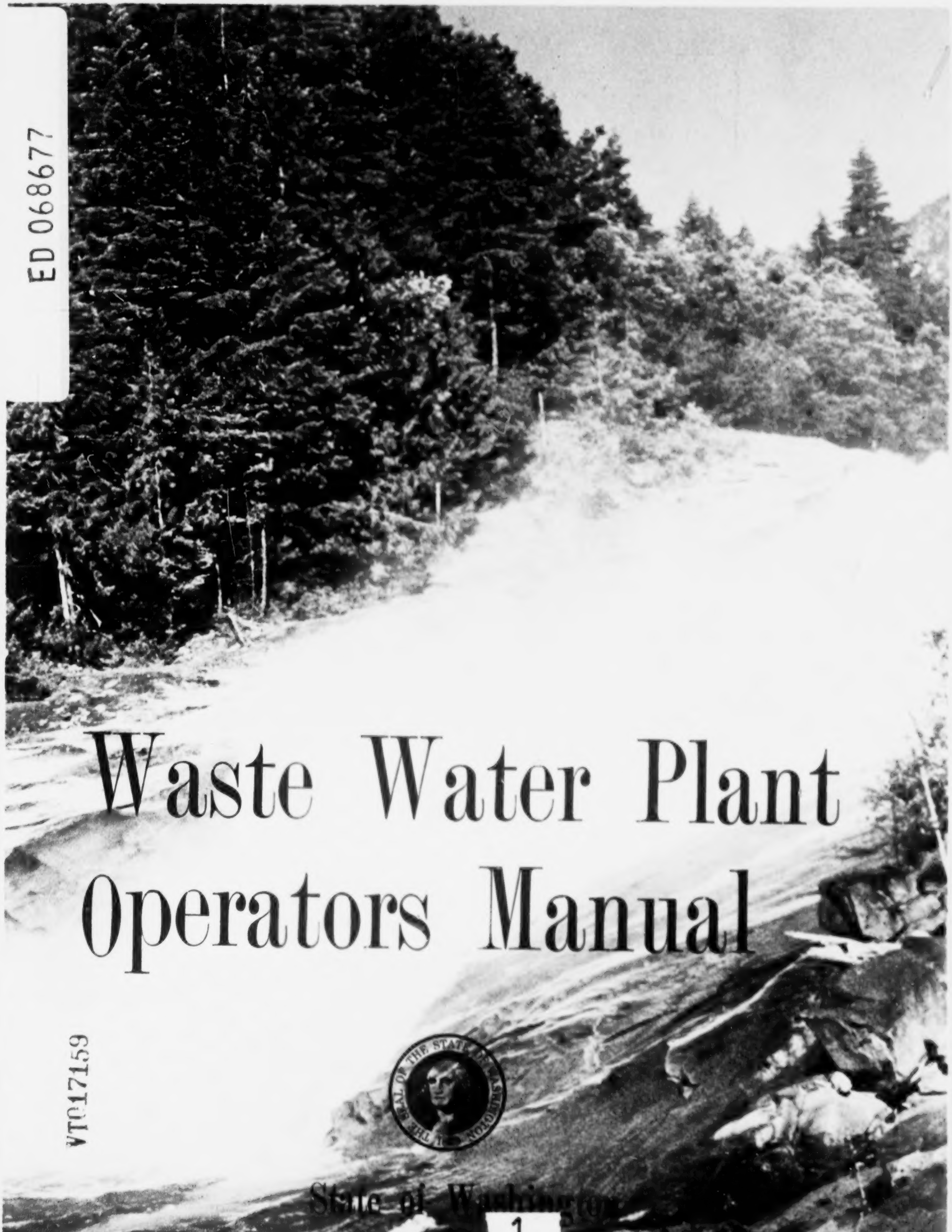

Waste Water Plant Operators Manual

VT017159

State of Washington

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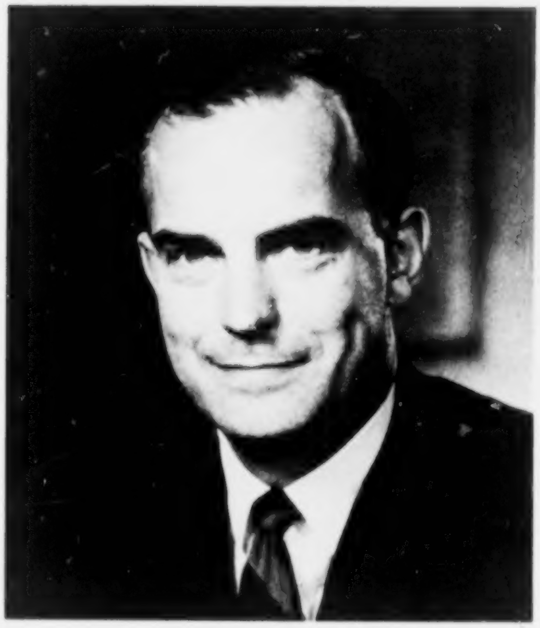

A STATEMENT BY THE GOVERNOR:

The desire to protect our environment and guide our growth has been one of the main thrusts of my administration. Our water quality standards must be kept high enough so that water may be utilized for many processes–to be used for human beings and for industry. By maintaining high water quality all the way down the various streams and rivers in the state, as well as in the lakes and water inlets, we have a better opportunity of assuring the conservation of this valuable resource for the generations of the future.

The Coordinating Council for Occupational Education, the State Health Department, the Pollution Control Commission, as well as those from Local Government, are to be commended for cooperatively developing training programs of which this manual is a part to assure high water quality for our State.

Daniel J Evans

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CHAPTER I

INTRODUCTION

PURPOSE OF MANUAL

In the investigation preceding the writing of this manual, it was found that sewage treatment plant operators needed a handbook, a reference text and a training manual. These three books were needed in a combined, concise model which would preferably be pocket-size and easy to read. It was soon apparent that a single book was going to be large and complex because the field covers so many items. However, it was decided to put together a manual which, under one cover, would contain a fairly good reference text and handbook, and would serve as a training manual for basic short course and certification programs.

The manual was written by a committee composed of operators, educators and engineers. The purpose at all times was to treat each subject according to the needs of operators. Enough theory was included to explain most of the material and to stimulate search for more explanation for those curious enough to pursue a subject which was not covered in sufficient detail.

OPERATOR'S ROLE

Sewage treatment plant operators have an important responsibility in water quality control. They have the responsibility for preventing the deterioration of the stream receiving the discharge from their plant. Their job is a day-by-day control which cannot be neglected without doing harm to someone else downstream from their location. Because the stream receives an effluent that still has organic material, chemicals and organisms, even with the best treatment available today, the stream must be considered as a portion of any sewage treatment plant. If it is a large stream, it may be able to accept some load without doing major harm downstream. However, streams in general are being used for so many things that all loads must be removed wherever possible. State and Federal stream standards have been set to emphasize that all treatable sewage must be treated before release to streams. The operator has the starring role in implementing these standards and keeping streams clean and useful for all beneficial purposes.

For many years sewage treatment plants have been at the end of the line. "Out of sight—out of mind" was the credo of city councilmen and populace alike. Traditionally, plants were put so far out into the woods and fields that only a few city employees knew their locations. Now, the situation has reversed. Neighbors have moved in around the plants. These people expect to live near the plants without having any nuisance effects. Operators must always be alert to prevent nuisance conditions which will antagonize their neighbors.

Emphasis on pollution control for the past several years has caused many people to visit sewage treatment plants to learn at first-hand how treatment is accomplished. This new public awareness and public contact creates a necessity for good, clean operation of plants and all auxiliary units to the plants. Clean, well painted buildings and equipment are a must. Odors must be kept to an absolute minimum. Appearance of both plant and personnel are vital to good operation. It is the responsibility of each operator to make sure that the image of sewage treatment is one of efficiency, cleanliness and neighborliness.

PURPOSE AND VALUE OF SEWAGE TREATMENT AND DISPOSAL

It is no longer possible to do as the natives of the jungle and simply move lock, stock and barrel to a new location when filth accumulates to an intolerable point. Sewage treatment was started as a result of disease epidemics associated with the filth from accumulated wastes and sewage. Rats, flies, and other disease-carrying pests made life miserable and could no longer be tolerated. Treatment processes were developed in response to a need to protect public health and welfare and to create a nuisance-free environment.

As knowledge was gained concerning treatment, it rapidly became apparent that receiving streams needed to be protected in order to maintain the best environment for aquatic life. Excess organic material remaining in the discharge from some of the early sewage treatment plants robbed the needed oxygen from fish and adversely affected their food chain. This resulted in a decrease in the number of catchable fish. At times large numbers of fish were killed or debris coated their environment so they could not obtain food.

Beneficial uses of water have increased to include domestic, municipal, mining, industrial and agricultural water supply; power development; as well as fishing, hunting, boating and other recreation activities. Pollution abatement has long been considered a use of water, but this use cannot be classed as beneficial. To some degree it is a necessary use, but every effort should be made to treat effluents before placing them in a stream. The State of Washington has set standards to insure that each beneficial use is protected from pollution from domestic sewage and other wastes.

Sewage treatment, as defined in this manual, includes disposal of all wastes carried in a sewerage system in a way that does not create a nuisance, interfere with aquatic life or trespass on beneficial uses of water or the environment.

HISTORY OF SEWAGE TREATMENT

Many modern sewage treatment plants are presently performing a continuous service to Washington communities. The plants vary greatly in design, construction, and operation; each plant is custom built to do a particular purification job, to safeguard public health and to permit beneficial use of streams, lakes and rivers.

It is hard to believe that modern sanitary engineering, especially as regards sewage and drainage, has developed since 1850. The beginning of the water carriage method of waste transmission is not certain. In early times sewers and water pipes were not connected to individual residences. Water drained from the ground and streets into the sewers. The streets received liquid and solid wastes from households. This situation created open sewers. Persons on the street after dark were endangered by the emptying of slop from windows overhead. It has been said that the custom of a male escort taking the outside of a walk originated here since this put the man more or less in the line of fire.

The first reference to indoor toilets comes from Elizabethan times. Seemingly the Queen's delicate nature prevented her from ordering a chamber pot or from strolling to the privy in her court yard when the situation demanded. The court consulted Sir John Herrington, a noted inventor, on this delicate situation, and Sir John obligingly invented an indoor toilet which was installed in the queen's bedroom. Thereafter and to this day this convenience has been known as "The John."

The United States is presently engaged in an unprecedented pollution abatement movement. People have finally recognized the need for cleaning up their environment. It is expected that increasing public support for advanced treatment will be seen in the next few years. Natural waters of the states are being used for recreation to the extent that the general public now sees the degradation that pollution control people have been trying to control for many years. They will demand that pollution be stopped which will require the allocation of considerable amounts of public funds. As a consequence more sewage treatment plants will be designed and constructed for obtaining an even higher treatment efficiency. Good operation of the plants will be an absolute necessity.

PERTINENT DEFINITIONS

In the sewage treatment field many definitions are used that have different meanings for various people. This section is designed to put down a few of the commonly used definitions so that all users of the manual will have a common agreement on use of the words. There is still some disagreement on a few of the terms. For this reason, a glossary is provided in Chapter IX explaining most of the words in some detail. These definitions are not intended as "legal" definitions. Legal definitions are generally included in specific state statutes dealing with pollution control.

1. **Pollution.** Pollution refers to such contamination or other alteration of the physical, chemical, or biological properties of any waters of an area, including change in temperature, taste, color, turbidity, silt or odor of the waters. It includes such discharge of any liquid, gaseous, solid, radioactive or any other substance into any waters of an area which, either by itself or in connection with any other substance present, will or can reasonably be expected to create a public nuisance or render such waters harmful, detrimental or injurious to public health, safety or welfare, or to domestic, commercial, industrial, agricultural, recreational or other legitimate beneficial uses or to livestock, wildlife, fish or other aquatic life or the habitat thereof.
2. **Wastes.** Sewage, industrial wastes, and all other liquid, gaseous, solid, radioactive, or other substances which will or may cause pollution or tend to cause pollution of any waters of an area.
3. **Sewage.** The water-carried human or animal wastes from residences, buildings, industrial establishments or other places. This also includes groundwater from infiltration and surface water from seepage or surface drainage.
4. **Industrial Waste.** Any liquid, gaseous, radioactive or solid waste substance or a combination thereof resulting from any process of industry, manufacturing, trade or business, or from the development or recovery of any natural resource.
5. **Waters of the Area.** Waters of the area include lakes, bays, ponds, impounding reservoirs, springs, wells, rivers, streams, creeks, estuaries, marshes, inlets, canals, the Pacific Ocean within the territorial limits of the United States and all other bodies of surface or underground waters, natural or artificial, inland or coastal, fresh or salt, public or private (except those private waters which do not

combine or effect a junction with natural surface or underground waters), which are wholly or partially within or bordering the state or within its jurisdiction.

6. **Marine Waters.** The Pacific Ocean within the territorial limits of the United States.

7. **Estuarine Waters.** The mixed fresh and sea waters in estuaries from the point of oceanic water intrusion inland to a line connecting the outermost points of the headlands or protective jetties.

8. **Standard or Standards.** Standard or standards refer to such measure(s) of quality or purity for any waters in relation to their reasonable and necessary use as may be established by pollution control authorities pursuant to State and Federal statutes.

9. **Fish and Other Aquatic Life.** All fishes, crustacea, mollusks, plankton, higher aquatic plants, and waterfowl.

10. **Sewerage or Sewerage Works.** All construction for collecting, transporting, pumping, treatment and final disposition of sewage.

11. **Treatment.** Any artificial or natural process to which sewage or other wastes are subjected in order to alter the objectionable materials and render them less offensive or dangerous.

12. **Disposal.** The final removal of end products from treatment facilities to sites where they will not create any further nuisance or damage to the health or welfare of people.

CHAPTER II

TREATMENT PLANT OPERATION

OPERATOR RESPONSIBILITY

A treatment plant operator is a public servant who has been placed in responsible charge of the operation and maintenance of a sewage or industrial waste treatment plant. He is directly responsible to either an elected or appointed public official. He is responsible for the successful operation of one of the most important, necessary, and costly services undertaken by a city or district. It is his duty to operate the treatment plant, effectively, efficiently, economically, and in such a manner that the public may point to it with pride.

The treatment plant operator becomes the guardian of his sewage treatment plant and the guardian of the receiving waterway insofar as it may be affected by the effluent from the plant. As such, he must be concerned with the ultimate use of the receiving waterway. He must always keep in mind the protection of the public health and welfare.

The Pacific Northwest Pollution Control Association, as a service to water pollution control plant operators and the communities which they serve, has adopted a program of operator certification. This certification program is entirely voluntary on the part of operators. The program in the State of Washington is administered by the Secretary of the Board of Certification, State Division of Health, Water Supply and Waste Unit, P.O. Box 1788, Olympia, Washington 98504. Although voluntary, this program in the State of Washington has met with a great deal of success, and nearly every operator who has participated in the program can testify as to the benefits derived from such participation. The importance of this program to operators who are in responsible charge of treatment works costing many thousands, and in some cases even millions of dollars, cannot be overemphasized. The aims of this particular program are as follows:

Improve the caliber of water pollution control plant operation and thereby assure maximum protection of the State's water resources and returns from the investment in treatment facilities.

Provide a means whereby those responsible for employment of water pollution control plant operators can readily determine their qualifications.

Elevate the status of water pollution control plant operators by setting forth their qualifications.

These needs will be fulfilled only by the active participation of every operator and acceptance of the program by all communities in the State of Washington.

1. **Specific Responsibilities.** It is the responsibility of any operator to maintain his treatment plant in a like-new condition at all times. To accomplish this, he must maintain excellent maintenance records and practice preventive maintenance to a high degree. This preventive maintenance must include physical as well as mechanical equipment such as buildings, pump stations, shops, tools, etc. Buildings must be kept clean and painted. Windows and floors should be kept clean and polished. Laboratory and offices and their equipment should be kept orderly and clean. Shop tools and shop equipment should be kept clean, neat and in their proper place. All vehicles should be kept washed, polished and serviceable. Routine maintenance procedures have been outlined in more detail in Chapter VII of this manual.

Other specific responsibilities of the treatment plant operator include maintenance of good records including a daily log. Operating data should be comprehensive enough to reveal the entire picture of the raw sewage characteristics, plant unit efficiencies, overall plant efficiencies, and the condition of the receiving waterway both upstream and downstream from the point of effluent discharge. The records should also include data concerning each individual industry connected to the sewer system. The data should cover volume, characteristics of waste, and the effect of industrial waste on the treatment plant. Flow and rainfall records should be kept to indicate the volume and source of unwanted infiltration. The daily log becomes one of the most important records that an operator can have. The daily log should contain everything of interest concerning the treatment plant each day. Daily plant logs have often been accepted as evidence in legal litigation relating to treatment plant operation and as such must be conscientiously kept.

Frequently, it is the responsibility of treatment plant operators to prepare a realistic annual budget for submission to city or district authorities. It must be remembered that such a budget is an estimate of the finances the treatment plant operator will require to operate and maintain his plant for the ensuing year. Each item in the budget should, therefore, be carefully estimated, and justified as fully as possible before its inclusion in the operating budget.

Many plant operators also have the responsibility to prepare an annual report to be submitted to city or district officials. Such a report should contain a good summary of the past year's operation, a copy of the last year's budget and actual expenditures, and carefully considered recommendations concerning additions or corrections that should be accomplished in the ensuing year to maintain a high degree of treatment.

Copies of all data, reports, budget estimates and the like should, of course, be maintained in the treatment plant files for ready reference at any time.

2. **The Operator's Role in Public Relations.** A good plant operator must assume the role of a public relations expert and "super" salesman in order to carry out all of his various responsibilities. He must insist that the treatment plant be kept running at all times and that additions and modifications to the plant be made as required in order to ensure that the plant is adequate to treat the load imposed upon it at all times. If a treatment plant is inadequate to treat the load imposed upon it, it is the responsibility of the operator to sell the need for providing additional treatment facilities to responsible officials.

Accurate records and sound recommendations incorporated in the annual report provide valuable documentation of the needs of the treatment operation.

There are numerous ways by which a treatment plant operator may "sell" his plant to the public. An operator should advertise his plant and be willing to conduct tours of the plant for school children, Boy Scouts, local civic groups, and local public health people. Many operators have enhanced the physical appearance of their treatment works by carefully planned landscaping. Many operators have enlisted the aid of local men's and women's garden clubs to assist with the landscape planning. These types of organizations are often interested and cooperative in helping an operator. Supervisors should encourage active participation in sewage works organizations and should help develop enthusiasm and public acceptance by insuring that the operators are at all times neat, clean, freshly shaven, courteous and knowledgeable. Many operators have been able to advertise their job and their treatment plant by inserting articles originating at the treatment plant in various news media. An example of this might be the keeping of accurate local weather information and providing the information to local radio stations or newspapers. This service not only provides valuable information to the citizens of the city or district but actually advertises the treatment plant as well.

3. **Employee Relationships.** It is the responsibility of the treatment plant operator to encourage his assistant operators to become more knowledgeable and enthusiastic in their jobs. This may be accomplished in a number of ways including attendance by assistant operators at various short courses offered by state universities, vocational technical institutes and community colleges; by urging attendance and involvement in operator's section meetings; and by conducting in-plant study sessions. Every treatment plant operator should become enthusiastic and involved enough to become certified in his chosen profession.

OFFICE AND MANAGEMENT PROCEDURE

A well organized office procedure is extremely valuable to an operator as well as city officials responsible for a community's overall treatment program. A treatment plant operator must maintain a very good, orderly, and up-to-date filing system including plant records, budgets, inventory, parts numbers, purchases and sources of supply, and copies of all outgoing and incoming correspondence. These files should be maintained in such a manner that any of this information is readily available. A good business card file indicating names, telephone numbers, and addresses of various manufacturer's representatives and salesmen with which an operator must conduct business is also a valuable aid.

1. **Accounting Procedures.** A good set of books should be kept in which all costs are recorded and charged against proper accounts such as maintenance, etc. Various accounts can then be broken down into individual segments including all major items of equipment in the plant, vehicles and various operating procedures such as sludge handling. This kind of record keeping will indicate which equipment is defective and must be replaced. The records will also show which operating procedures are uneconomical and may justify correction or replacement. This type of cost data also provides a valuable tool in the preparation of each year's budget.

2. **Personnel.**

A. Personnel Records. Good personnel record procedures are very important. These records should contain such information as the rate of pay, vacation time, sick leave, and hours worked by each employee at a treatment plant. These records become valuable when the operator needs to justify increases in pay scale or additional personnel for his operations. Complete and accurately kept personnel records also can be a valuable aid in avoiding misunderstanding between employees and administrative personnel.

B. Employee Training. Every chief operator should have a definite system in mind for training and educating existing as well as new personnel.

Such programs should include both on-the-job training by means of demonstrations and technical training such as is contained in this manual.

C. Sources of Information. Sources of information for all personnel connected with operation of a treatment plant include numerous publications by the Water Pollution Control Federation, the Pollution Control Commission, and additional technical textbooks and handbooks such as this operators manual. Other obvious sources of information include up-to-date, as-built plans of the treatment plant being operated as well as equipment operation and maintenance manuals provided by the manufacturers of the various equipment contained in the plant. Plans for any treatment works should be kept up-to-date whenever any changes, however small, are made in the system. The importance of an overall complete set of as-built plans cannot be overemphasized since these plans provide the only readily available means of determining size and location of equipment, valves, and pipelines which may be buried or otherwise hidden. Whenever an expansion of an existing facility is required, good accurate as-built plans will prove valuable to a city or district and will usually result in a considerable monetary saving at the time an expansion becomes necessary.

3. **Plan Reading and Interpretation.** The word "plans" as used herein may be defined as a means of communicating the ideas of the design engineers concerning items that are to be built or constructed. Plans are also used to express alternate ideas when studying any particular problem. Many people believe that reading engineering or architectural plans is difficult. This is not true. The engineering and architectural draftsman follows rigid rules for describing his ideas on plans. These rules are few and not difficult to learn. As such, plans are merely a pictorial representation of what a completed treatment plant is to look like. The initial use of the plans is of course made by the contractor, who constructs the treatment works. Plans must, therefore, be complete enough to answer any questions concerning the physical construction of all portions of a treatment works. In addition to plans for any treatment works, a set of specifications are required.

Specifications normally contain two major parts. The first part of the specifications includes the legal documents involved with actual construction of a particular job. These documents include a signed contract as well as various other items such as bond and insurance requirements which must be met by a contractor. The other portion of the specifications contains technical descriptions of the various items which go to make up a finished job. Included would be technical descriptions of equipment, descriptions of how excavation and backfill is to be performed, and requirements for various materials to be used in the construction such as steel, concrete and wood. It is usual for specifications to name a specific manufacturer's equipment as a guideline as to what quality of equipment is expected. The naming of a specific item such as a Worthington pump does not necessarily mean that a Worthington pump will in fact be purchased. In most cases, it is possible to choose equipment made by other manufacturers which is of similar quality; and accordingly, in the example just listed, the actual piece of equipment supplied may in fact be a pump from some other manufacturer. In all cases, however, the operating characteristics of the equipment will be essentially the same as contained in the specifications. For this reason, it is necessary to maintain accurate files of various manufacturer's publications concerning equipment actually installed at a plant.

Operating personnel must be able to interpret plans and specifications as an aid to operation of any given treatment plant. For example, it is frequently necessary for an operator to trace out a given flow pattern through a maze of valves and pipes in order to determine various alternate operating procedures or to locate some trouble spot which may have occurred in the piping system. Because of this, operators must be familiar enough with plans in order to be aware of various alternate operation methods built into their plant by designing engineers. It is not the purpose of this manual to teach plan reading as such; however, it is suggested that valuable assistance with regard to the reading of plans can readily be obtained at local offices such as the office of city or district engineer as well as from pollution control personnel who periodically visit treatment works. Operators should not be reluctant to ask questions however trivial they may seem.

PHYSICAL PLANT

The importance of cleanliness and orderliness at any treatment plant has already been discussed in this chapter and will be further explained in Chapter VII. Operators should also be aware of the necessity to maintain safe working conditions at all times and should never undertake any task which they feel unqualified to do. Public relations have already been previously discussed as an aid to overall plant operation. An operator should always have a good image of himself and of his job. He should never feel that operation of a treatment works is a degrading occupation. Probably, the most effective way to convince one's self of the importance of an operator is to consider the cost of the treatment system over which an operator has responsible charge. Common sense should tell any operator that it is simply not good business sense for a city or district to spend the thousands of dollars required for effective treatment and then put the entire operation into the category of an occupation which is beneath the dignity of any capable person.

With respect to the operation of the physical plant, operators should intuitively see that reliability of the equipment provided and used in the treatment process must be the backbone of any statewide water quality control program. Without proper operation at all times of all treatment facilities, deterioration of receiving waterways must be inevitable.

EQUIPMENT AND INSTRUMENTATION

1. **Catalogs.** Operators should maintain all equipment catalogs and data supplied by manufacturers. They should also obtain copies of catalogs published by various laboratory equipment and chemical supply houses so that they will be in a position to order needed test equipment and chemicals.

2. **Maintenance Procedures.** Chapter VII of this manual indicates general maintenance procedures for most equipment found in treatment plants. In addition to the information contained in Chapter VII of this manual, it is suggested that each operator obtain and use a copy of the Water Pollution Control Federation Manual of Practice Number 11, entitled Operation of Waste Water Treatment Plants. This manual is available from the Water Pollution Control Federation, 3900 Wisconsin Avenue, Washington, D. C. 20016.

3. **Repairs.** Operators should schedule repair work to have the least effect on treatment effectiveness whenever this is possible. Repairs should not, however, be delayed if such delay will result in extensive damage to the equipment. Operators are cautioned that they are required to report to the Pollution Control Commission whenever it becomes necessary to bypass all or portions of the treatment system provided.

CHAPTER III

COLLECTION OF SEWAGE

DEFINITIONS AND CONCEPTS

1. **Background.** The basic purpose of waste water piping systems or sewer systems is to collect and transport waste waters to a point of treatment or disposal. All sewerage systems rely on relatively simple hydraulic principles for operation. These principles, though evident in practice, required many centuries of study before they were understood. Even the ancient Greeks, whose knowledge and achievements were unparalleled until the past two centuries, were unable to develop the ideas of three dimensional flow variables or water pressure functions.

The dangers of the accumulation of human wastes in living quarters was understood by the ancients, but the concept of water-carriage of fecal or other wastes was not utilized to any great extent until the early 1800's. There is archeological evidence of waste water piping systems in India around 3750 B.C. and Bagdad around 2500 B.C. The oldest sewer still in existence is the Cloaca Maxima in Rome, an arched sewer built in the First Century A.D. for carrying wastes from the Roman Forum to the Tiber River. These are, however, notable exceptions.

The City of Hamburg, Germany, boasts the first engineered sanitary sewer system. This was constructed in 1843. Before this time, nearly all sewer systems carried a combination of sewage from households, or domestic wastes, and the land runoff from rain and flooding, or storm drainage.

The concept of the separation of storm drainage and domestic wastes did not become generally accepted until sewage treatment became a necessity. Then it was obvious that treatment systems which were designed on the basis of hydraulic functions could not accomplish the required pollutant removals under the extreme variation in flows imposed by storm runoff conditions. Cost of facilities for complete treatment became prohibitive.

Most of the major cities in the United States were developed along water courses or other natural waters. The general lack of information concerning the problems inherent to combining sewage and storm water resulted in many older sections of major cities in this country using partially combined systems carrying both storm drainage and domestic waste.

2. **Types of Sewerage Systems.**

A. Sanitary Sewers. An organized piping network which carries wastes normally associated with household water uses from the primary source, the residential or commercial building, to a point in the system where treatment and/or disposal is accomplished.

B. Storm Sewers. A controlled system of open water courses, culverts and closed piping which carries storm water runoff and other sources of land drainage to a river, stream, or other water course.

C. Industrial Sewers. A network of piping designed or constructed to carry the used process waters from wet manufacturing or process industries to a point of treatment or disposal. Such systems are often unique in the materials of construction due to the corrosive nature of many strong industrial wastes.

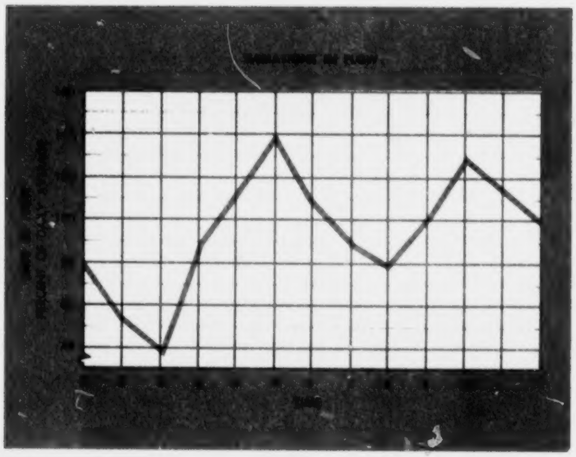
D. Combined Systems. These include any combination of the above waste waters, flowing in a single pipe. This usually results in an exaggeration of the objectionable characteristics of each. A few examples are:

(1) Storm and sanitary waste water combinations require special considerations due to the necessity of treating only the sanitary wastes. Such treatment is usually not required for storm waters alone due to the low nutrient value of storm waters and the highly variable flows.

(2) Sanitary and industrial waste water combinations may intensify the adverse effects of both due to the occurrence of bacterilogical or chemical reactions in the combined wastes. Objectionable effects on the piping and treatment processes may result.

3. **Quantities of Sewage.**

A. Domestic or Sanitary Wastes. Normal household use of water which is used and then discharged to the sewer generally varies from 15 gallons per person per day to as high as 100 gallons per person per day. Generally, the higher figure of 100 gallons per person per day is used for designing treatment units and pumping stations with some factor added for short-term overloads. This water usage includes wash water, both bath and laundry, food rinsing operations, toilet use and recently, dilution water for household garbage disposal units.



VARIATIONS IN FLOW

Figure (3-1)

Dry-weather flows, based on a recent compilation of 1966-1967 data from nine major sewage treatment plants in the Pacific Northwest, range between 62 and 137 or an average of 107 gallons per person per day. Again, the same plants showed a variation, based on average yearly flow and average maximum monthly flow, of from 86 to 171 for an annual average of 150 gallons per person per day and from 131 to 272 for an average maximum monthly flow of 222 gallons per person per day. The evidence of the storm water effect on waste flows becomes quite obvious when plant flow records are studied with this in mind.

There are a number of factors which confuse the accurate prediction of waste water quantities. Two of these are: documented evidence of metered water uses by domestic users; and, infiltration of surface and groundwater into sanitary sewers.

It has been well documented that normal water usage by households on an annual average basis exceeds 200 gallons per person per day. This fact would seem to indicate that sewage flows should more closely approach this figure. It is also a fact that sewage flows do not come within 50 percent of this figure normally. This leads to the following conclusions:

(1) There are major uses of domestic water which does not result in increased sewage flows, i.e. lawn sprinkling.

(2) Metering of household users does not account for losses through pipe leakage, irrigation, and lawn watering, etc. Infiltration of surface and groundwaters and illegal connections further complicate the problem due to their dependence on the intangibles of original sewer construction techniques, sewer condition and inspection both of the original construction and of the house services. This item of infiltration will be discussed in more detail later. Table 3-1 is a tabulation of some common waste water flows. These are for estimating only and are by no means limiting quantities.

It should be noted that sewage flows seem to vary directly with the social and economic status of a community. As the standard of living increases, so do the waste flows. This is a reflection of the ability to purchase labor-saving appliances for washing, and of higher hygienic standards. This factor can have a considerable effect on sewerage systems since essentially the same amount of organic waste is contributed by each person in a day and if the dilution is reduced, problems due to strong sewage are increased. Therefore, it is entirely possible for wastes from lower socio-economic areas to shorten the life of a sewerage system measurably unless precautions are taken.

B. Storm Flows. Storm water runoff quantities are extremely difficult to predict since they are dependent upon rainfall intensity and duration, soil characteristics, amounts and types of vegetation, ground slope, shape of drainage area, etc. In the case of sewers designed for combination flows, heavy storms will frequently introduce water into the system at 80 to 100 times the dry-weather sanitary flow. Sewers originally designed for sanitary use only, often carry 5 times the dry-weather flow during heavy rainfall periods.

Probably, of greatest importance to the waste water treatment plant operator are the illegal sources of storm runoff contributing to the sanitary sewers. The most frequent violation is the individual householder who connects his roof drains to the sanitary sewer. The effects of this type of connection are felt almost instantly in the sewer system. Illegal catch basin connections are also readily noticeable in a sewer system.

In general, the sources of storm water introduction to sewer systems may be identified by the lapse of time between the beginning of significant rainfall and the increase in sewage flows. Catch basins, roof drains, open manholes and open service connections produce an almost immediate increase in flow and a quick reduction in flow when rainfall decreases. Footing drains, broken piping, and other underground sources of storm water intrusion cause a slow but relatively long-lived response in waste flows. This is a result of the water having to saturate the soil and penetrate many feet into the ground before entering the sewer.

The best protection against the intrusion of storm water into a sanitary sewer system is conscientious inspection of all sewer construction, particularly, house service connections. If workman-

TABLE 3-1

ESTIMATING VALUES FOR WASTE QUANTITY

Type of Establishment	*Gallons per Person per Day*
Small dwellings and cottages with seasonal occupancy	50
Single-family dwellings	75
Multiple-family dwellings (apartments)	60
Rooming houses	40
Boarding houses	50
Additional kitchen wastes for nonresident boarders	10
Hotels without private baths	50
Hotels with private baths (2 persons per room)	60
Restaurants (toilet and kitchen wastes per patron)	7 to 10
Restaurants (kitchen wastes per meal served)	2- 1/2 to 3
Additional for bars and cocktail lounges	2
Tourist camps or trailer parks with central bathhouse	35
Tourist courts or mobile home parks with individual bath units	50
Resort camps (night and day) with limited plumbing	50
Luxury camps	100 to 150
Work or construction camps (semipermanent)	50
Day camps (no meals served)	15
Day schools without cafeterias, gymnasiums, or showers	15
Day schools with cafeterias, but no gymnasiums or showers	20
Day schools with cafeterias, gymnasiums, and showers	25
Boarding schools	75 to 100
Day workers at schools and offices (per shift)	15
Hospitals	150 to 250+
Institutions other than hospitals	75 to 125
Factories (gallons per person per shift, exclusive of industrial wastes)	15 to 35
Picnic parks (toilet wastes only), (gallons per picnicker)	5
Picnic parks with bathhouses, showers, and flush toilets	10
Swimming pools and bathhouses	10
Luxury residences and estates	100 to 150
Country clubs (per resident member)	100
Country clubs (per nonresident member present)	25
Motels (per bed space)	40
Motels with bath, toilet, and kitchen wastes	50
Drive-in theaters (per car space)	5
Movie theaters (per auditorium seat)	5
Airports (per passenger)	3 to 5
Self-service laundries (gallons per wash, i.e., per customer)	50
Stores (per toilet room)	400
Service stations (per vehicle served)	10

ship is good in the initial construction of sewers, and private homes and businesses are not allowed to connect storm water drains to the sewers, then wild fluctuations in flows during heavy rainfall periods will be reduced to a minimum. Experience with tightly controlled utility districts has proven this to be true.

C. Industrial Wastes. Industrial waste waters vary with each plant and each process. No two industrial operations are the same. For this reason, these wastes are extremely difficult to predict, either in quantity or quality. Also, since economics play such a major role in industrial plant operations, waste characteristics tend to fluctuate with the stock market as well as with such factors as plant management, responsibility and equipment reliability.

Industrial waste problems as they relate to this viewpoint will be further explored in subsequent chapters.

D. Combination Sewerage Systems. By way of maintaining some consistency in terms, hereafter the reference "combined sewer" will refer to those sewers carrying both storm water runoff and sanitary wastes.

As was mentioned previously, under Background, most established U. S. cities have some combined sewers. These are characterized by the presence of numerous emergency overflow and bypass structures in the sewer system. These are utilized for the protection of downstream mechanical equipment and are theoretically supposed to have capacity to carry three times the dry-weather flow before overflowing. This is generally an optimistic hope by regulatory agencies.

Flow in combined sewer systems follows, more or less closely, the intensity of rainfall over the contributing area or basin. Often street catch basins and building roof drains are connected to such a system making the results felt downsewer almost immediately.

Generally, storm flows are estimated rather than measured due to the difficulty in gauging high flows in relatively small conduits and the frequency of overflows and bypasses. Quite often storm flows will exceed the dry-weather flow by 10 times or more depending on the intensity of rainfall. Often sewer lines designed for sanitary flow only, but subjected to illegal catch basin and roof drain connections, will back up and overflow manholes, causing flooding and a wide spread contamination problem.

In summary, combined sewers cause many problems due to standing of sewage solids during dry periods and flushing of these materials into rivers and streams during storms. Maintenance problems are compounded due to the necessity of providing diversion structures with attendant mechanical and hydraulic appurtenances.

E. Infiltration. Infiltration is the intrusion of ground or surface water into a sanitary sewer system due to an interruption in the watertight integrity of the system. This is most often caused by pipe breakage, joint failure, high ground water levels and illegal connections.

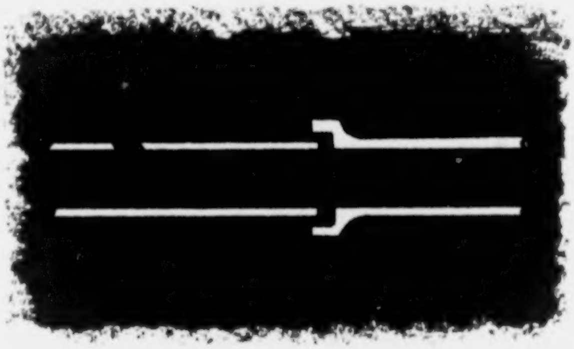
Prior to the development of the rubber-ring pipe joint, pipes were joined and sealed with a cement mortar. Such joints tend to shrink upon setting and reduce the effectiveness of the watertight connection. The aging process breaks down the bond between the pipe and the mortar and after a period of time complete failure may occur. Thus, mortar joints subject to varying levels of groundwater, deteriorate to the point at which sewer lines act in much the same manner as an open joint field drain, admitting massive amounts of groundwater with every rise in the water table.

In addition to the above mentioned causes of infiltration, pipe breakage, joint failure and illegal connections, other causes have been found to be common. Some of these are:

(1) Poor workmanship during construction, allowing unplugged tees and wyes, unsealed manhole joints, thin or porous manhole floor slabs and use of highly porous or cracked sewer pipe.

(2) Corrosion due to chemically reactive waste waters, uninsulated connection of pipes of two different electrically reactive metals and reactive aggregate in the pipe material itself.

(3) Miscellaneous causes—leaky manhole covers and frames, the root intrusion (usually a result of a poor joint or broken pipe), illegal connections and pipe breaks from poor maintenance practices.



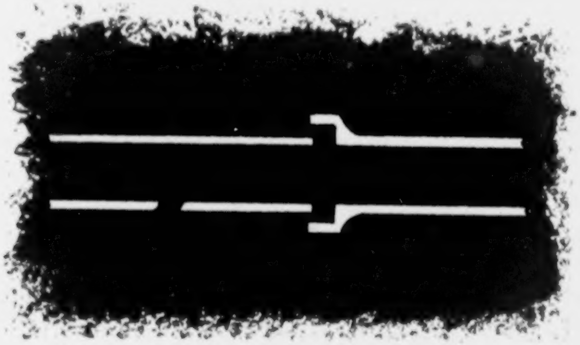
Infiltration, ground water leaking into the pipe line through loose joints or Fractures.

Figure (3-2)

F. Exfiltration. Leakage of sewage and other wastes from the piping network into the surrounding ground or groundwater is termed exfiltration. This is a generally uncommon phenomena due to the low pressure to which sewers are subjected. As a rule, piping systems exhibiting loss of sewage through leakage will experience very great infiltration during wet weather conditions. Therefore, it is seldom that exfiltration will occur during the dry season in the absence of infiltration during wet weather.

Leakage from sewers in the dry periods of the year may cause groundwater contamination, collection of sewage solids in the pipes and generation of dangerous and explosive gases in the sewer systems. For these reasons, exfiltration may be potentially more harmful than infiltration. However, it is much less common.

Methods of detection are generally developed around a process of elimination much like those for infiltration detection. They amount to the measurement of dry-weather flows and the determination of consistency throughout the sewerage system. Consistency of flow continues to be a much-used method of detecting irregularities in a sewage system. Closed circuit television scanning of sewer systems is a fairly recent innovation and has proven to be an excellent tool for aiding maintenance and repair of existing systems.



EXFILTRATION: WATER LEAKING OUT OF THE PIPELINE INTO THE SOIL
Figure (3-3)

4. **Classification of Collection System.**

A. House Services. Individual service connections constitute those sewers which extend from a wye in the street or intercepting sewer to the single connection with the house or building waste water plumbing system. Such sewers are generally built as far as the private property line by the municipality or utility district under the same contract as the street sewer. The property owner then must construct and maintain that portion of the house service which is on his property.

Ideally, house services are located so as to facilitate the connection of all the building waste water piping to a single outfall line. Unfortunately, due to a lack of control many buildings must be plumbed into several interconnecting pipes before connection can be made to the service provided in the street.

As in other areas of management, the control of house service construction from the building to the property line is not consistent with all public entities. Each municipality or utilities district has a different viewpoint on control of service connection construction, and consequently, these seemingly unimportant parts of the overall system often are major contributors of storm water infiltration to the system and can prove to have public health significance, as well. Surveillance of this individual construction must be considered of major importance due to the number of such installations.

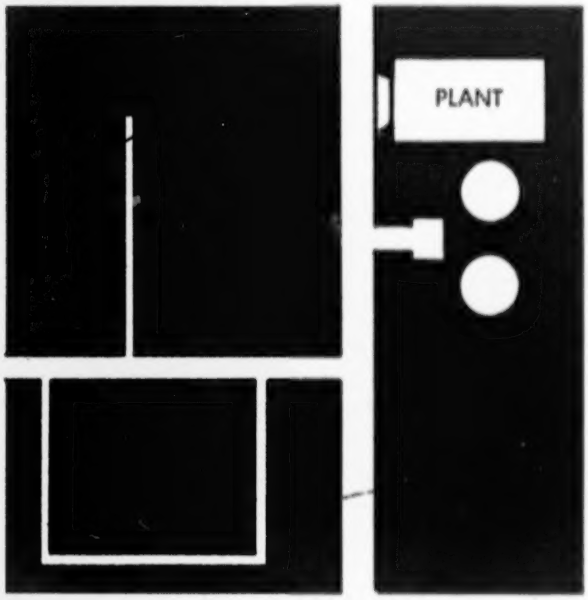
B. Lateral Sewers. If there is no major contributing source to a sewer line other than house or building services, then it is considered to be a lateral sewer. Laterals are the upper ends of the sewer system network and as the capillary veins in the body carry waste from each individual living cell, the laterals make physical contact with each house served through the service connection. Such sewers are located so as to afford maximum service to individual homes and are usually sized to receive no less than 300 to 350 gallons per person per day.

It is advantageous to construct laterals in streets or other public rights-of-way in order to avoid the legal complications of dealing with private owners. However, often it is necessary to procure rights-of-way through private property. These are called easements and constitute a legal permission to construct and maintain sewers by a public body on private land. Such agreements are acquired either by negotiation or condemnation. In either case some fair value is placed on the land so used and the constructing entity must pay for the use of the land for sewers and maintenance.

C. Trunks and Mains. The sewers which receive flow from several lateral sewers are referred to as trunks or mains. They are generally sized to receive sewage flows of at least 250 gallons per person per day with the idea being that the significant length of tributary laterals will stabilize the peak flows to the trunk sewers. These trunk or main sewers are located so as to most efficiently utilize the natural terrain in intercepting the lateral sewers. Trunks do not necessarily follow street layouts; however, it is often advantageous to do so because of maintenance and repair considerations. Historically, trunks and mains were constructed to carry wastes from lateral sewers to a point of discharge, usually a receiving stream.

D. Interceptors. Due to the availability of construction funds through governmental grant programs, the term "interceptor sewer" has had widely varied interpretation. However, practically speaking, an interceptor is a major sewer line which accepts the sewage flow of at least three to five times the dry-weather flow of trunks and mains. Due to the history of trunk sewers discharging into rivers and streams interceptor sewers generally follow natural drainage courses and divert trunk sewer discharges from the streams to treatment facilities, pumping stations or outfalls. In many communities treatment of sewage becomes a necessity some time after construction of sewers. Consequently, interceptors are often located so as to divert existing outfalls and, as such, parallel existing basin drainage ways.

E. Outfall Sewers. The last link in the sewer line which carries used water back to a natural watercourse is referred to as an outfall or effluent sewer. An outfall sewer is sized in accordance with the interceptor sewer and is sometimes merely an extension of such an interceptor. The sewer which carries treated wastes to the receiving stream is also termed an outfall and falls into the category outlined in the first sentence above. The outfall sewer is located so as to convey the waste water to or into the receiving body of water with the greatest efficiency of the use of natural fall and the production of the least undesirable effects of this intrusion on nature's plan.

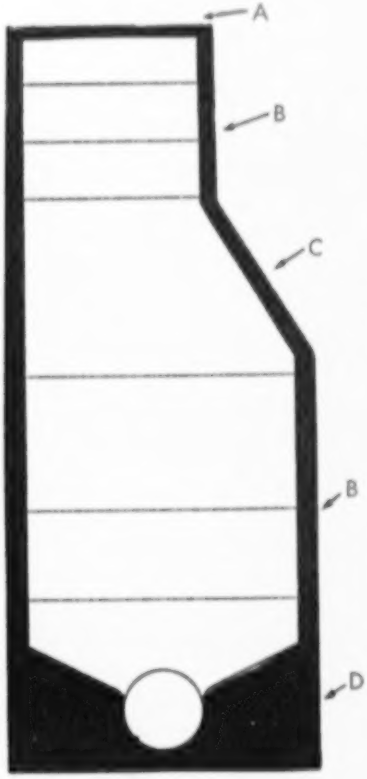


Typical layout of a City Sewer System

Figure (3-4)

F. Manholes and Appurtenances. A manhole is a readily accessible inspection and maintenance port to an otherwise inaccessible utility. Sewer manholes consist of a shaft extending from the ground surface or above to the open flow channel formed in the floor of structure. Manholes are constructed at points in the piping network at which problems may be expected to occur—changes in grade, alignment, pipe size or pipe shape. In addition due to practical limitations of pipe cleaning equipment, manholes are generally provided on straight runs of pipe at distances of from 300 feet to 500 feet.

Materials of construction include concrete, brick and metal (usually corrugated steel). In recent years smaller manholes, 72-inch inside diameter and less, have been constructed of precast reinforced concrete pipe sections since these units are readily available and easily handled. Poured-in-place concrete manholes are usually used in providing special maintenance and inspection ports in large pipe, 48-inch or more. Such manholes must be something more than a simple shaft and will usually have one or more observation and sampling platforms built into the structure. Other special structures, such as very shallow manholes, are generally field-constructed.



A. COVER

REINFORCED CONCRETE FRAMES AND COVERS ARE USED EFFECTIVELY IN THE CAPPING OF THE REINFORCED CONCRETE PIPE MANHOLE.

B. RISERS

PRE-CAST REINFORCED CONCRETE PIPE RINGS OF VARYING LENGTHS ARE USED AS RISERS SO THAT ANY DESIRED HEIGHT OF THE MANHOLE MAY BE ACCOMPLISHED.

C. TAPER
(STRAIGHT BACK ILLUSTRATED)

THE STREET LEVEL DIAMETER IS EXPANDED TO A WORKING DIAMETER BY MEANS OF THIS SPECIAL PRE-CAST SECTION.

D. BASE

PRE-CAST AND CAST-IN-PLACE BASES ARE MADE IN ACCORDANCE WITH SPECIALIZED METHODS OF MANUFACTURE ENABLING JUNCTIONS, CHANNEL BENDS AND BENCHINGS TO BE FORMED TO ENGINEERS' EXACT REQUIREMENTS.

Figure (3-5)

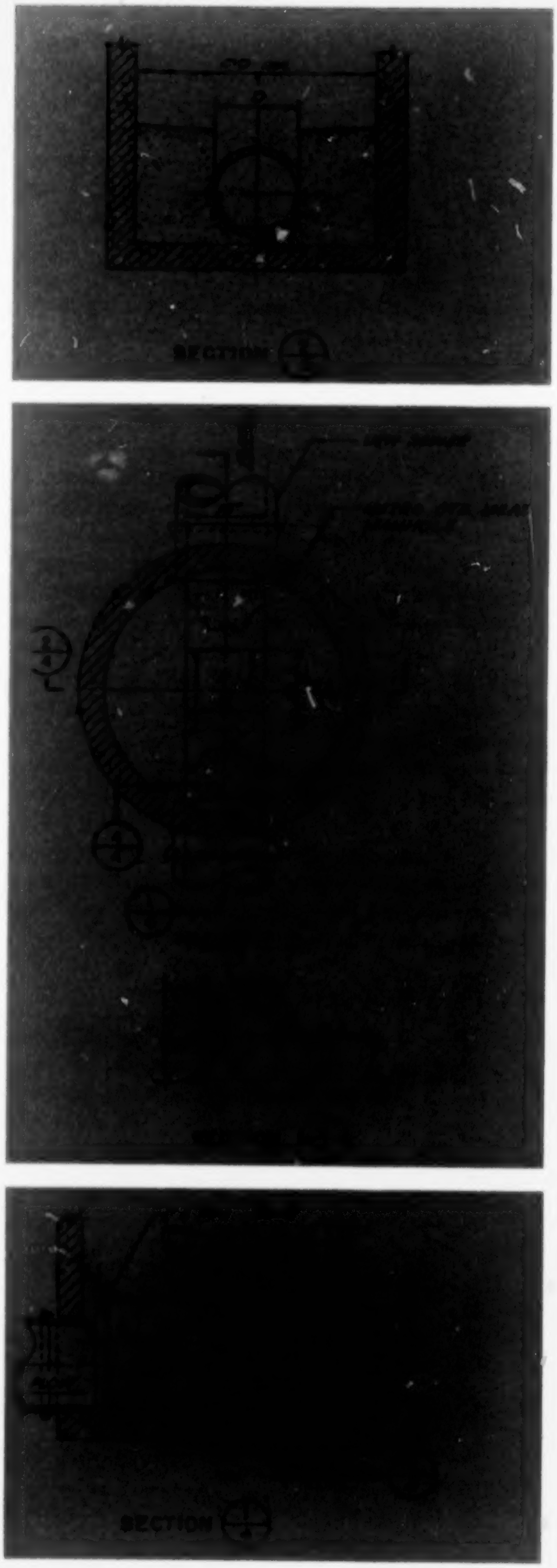
Manhole covers and frames are generally fabricated from gray cast iron. Weights and gauges of metal vary depending on the traffic conditions and loads to be carried. Generally manhole frames and covers are machined on the bearing surfaces to afford a reasonably tight fit thus minimizing an uneven distribution of traffic weight. Covers are often perforated to increase ventilation of sewers; however, this practice nearly always leads to infiltration and grit intrusion into sanitary sewers and thus is not recommended.

Following are some special structures which fall into the general category of manholes.

(1) drop manholes. A standard manhole intercepting flows from sewers having more than two feet elevation difference between incoming and outgoing sewers. To protect maintenance personnel and avoid stranding of solids in the manhole, an outside drop, in the form of a tee and an elbow in the incoming sewer, directs the flow through the side of the manhole at floor level. The outside drop assembly should be encased in concrete.

(2) lampholes and cleanouts. A wye and capped riser on the end of a sewer line is generally referred to as a "cleanout." Such an opening is for rodding and cleaning equipment only and is not applicable as an inspection port. In older systems, such openings were constructed using a tee connection on the sewer so that a light could be lowered into the line for inspection from the next downstream manhole. Since such "lamping" of sewers is rarely practiced today and modern sewer cleaning equipment is not applicable to a tee connection, such facilities are usually constructed with a wye on the sewer and referred to as "cleanouts."

(3) metering manholes. These are manholes constructed so as to incorporate some flow measuring device. Usually, the actual flow recording equipment is housed elsewhere due to excessive moisture in the manhole and a signal is relayed from the prime device in the manhole to the recorder. Such a system is often used as a basis for charges connected with contractual agreements for sewer service.



STANDARD MEASURING MANHOLE

Figure (3-6)

(4) siphon manholes and flush tanks. These are structures whose prime function is the storage of sufficient quantities of sewage or water to periodically flush a downstream sewer. A siphon system is employed to provide the predetermined amount of flushing water and the structure is so constructed to provide the storage necessary.

Flush tanks employ the use of fresh water from adjacent drinking water systems to ensure a constant flow to the dosing chamber or storage basin. Due to the fact that backsiphonage of sewage into the drinking water system is a definite hazard in these installations, sewer regulations now prohibit the use of flush tanks in new construction.

(5) flow control manholes – diversion manholes. In the case of overloading of sewers in one section of a system, sometimes a parallel line will be built to relieve the overloaded sections. On the upstream end of the overloaded line a structure must be provided to restrict the flow to the pipe capacity and divert the excess to the new line. This structure is termed a "diversion manhole". Most often an overflow weir will be used to automatically control flow. However, adjustable gates have been employed for this purpose.

A modification of the diversion manhole is used in combined systems to divert storm water excesses to a drainage course or storage chambers. This serves to protect mechanical equipment from flooding and also reduces the overloading of sewers and widespread public health hazards from raw sewage overflows in residential developments.

MATERIALS OF CONSTRUCTION

1. **Criteria for Selection.** The Water Pollution Control Federation publication "Manual of Practice No. 9, Design and Construction of Sanitary and Storm Sewers," 1960, outlines the following items to be considered in the selection of pipe materials:

A. Flow Characteristics – Friction Coefficients.

B. Life Expectancy and Use Experience.

C. Resistance to Scour.

D. Resistance to Acid, Alkalies, Gases, Solvents, Etc.

E. Ease of Handling and Installation.

F. Strength to Resist Structural Failure.

G. Type of Joint – Watertightness and Ease of Assembly.

H. Availability and Ease of Installation of Fittings and Connections.

I. Availability in Sizes Required.

J. Cost of Materials, Handling and Installation.

2. **Concrete Sewer Pipe.**

A. Characteristics. Concrete for pipe is composed of a dense mixture of portland cement and graded stone aggregate. It is formed between highly polished steel forms inside and rougher outer forms for the exterior finish. The porosity of the finished product is directly dependent on the compaction of the mix in the forms and the characteristics of the aggregates and chemical admixtures.

Unreinforced-concrete pipe in sizes 4 to 24 inches in diameter and reinforced-concrete pipe in sizes 8 to 120 inches in diameter are generally available for gravity sewers. In some localities vertically cast and vibrated pipe is produced in diameters above 120 inches. A number of joint designs are available depending on the degree of watertightness required. Gasketed tongue-and-groove joints can be used when infiltration is a problem. Reinforced-concrete pressure pipe and prestressed-concrete pressure pipe are used for force mains, submerged outfalls, inverted siphons, and for gravity sewers where absolutely tight joints are required.

Concrete pipe may be manufactured to almost any reasonable strength requirement by varying the pipe wall thickness and the percentage and shape of the reinforcing cage. A number of jointing methods are available depending on the tightness required and the operating pressure within the sewer line.

The advantages of concrete pipe are the relative ease with which the required strength may be provided, the wide range of pipe sizes, the long laying lengths varying from 4 to 30 feet depending on the type of pipe and the manufacturer, and the rapidity with which the trench may be opened and the trench backfilling done. When necessary, concrete pipe may be installed by the jacking method.

The disadvantages are that it is subject to corrosion where acids are present in the sewer, where velocities are not sufficient to prevent septic conditions and where wastes are highly acid or contain large amounts of sulfates. Protective linings should be used where excessive corrosion is likely to occur. Studies by the City of Chicago indicate that the use of Type II portland cement and air entrainment will increase the corrosion resistance of concrete. Only dense high-quality concrete should be used in concrete exposed to sewage or industrial wastes.

When specifying concrete pipe, the pipe diameter, class or strength, the method of jointing, the type of protective coating and lining if any, and any special concrete requirements should be stipulated.

3. **Asbestos-Cement Pipe.**

A. Characteristics. Pipe of asbestos fiber and cement, in sizes 4 through 36 inches in diameter, is available and is used in gravity and pressure sewerage systems. Jointing is accomplished by compressing rubber rings between factory-machined pipe ends and sleeves of the same material as the pipe. Asbestos-cement or cast-iron fittings are used for gravity sewers; cast-iron fittings are usually for force mains.

The advantages of asbestos-cement pipe are light weight and ease of handling, long laying lengths, tight joints, rapidity with which pipe may be laid and the trench backfilled, and corrosion resistance to most natural soil conditions. It is subject to corrosion by acid and highly septic sewage just as is concrete pipe.

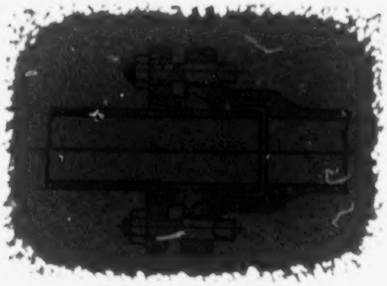
4. **Cast Iron Pipe.**

A. Characteristics. Cast-iron pipe in sizes from 4 to 48 inches in diameter with a variety of jointing methods is used for pressure sewers, for sewers above ground surface, for submerged outfalls, for sewage treatment plant piping, and for gravity sewers where absolutely tight joints are essential.

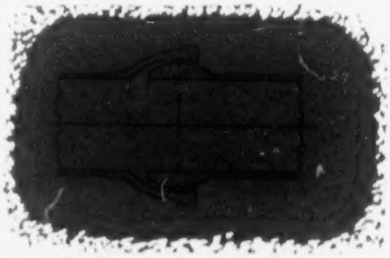
The advantages of cast-iron pipe are long laying lengths with tight joints, ability, when properly designed, to withstand relatively high internal pressures and external loads and corrosion resistance in most natural soils. It is subject to corrosion by acid or highly septic sewage and by acid solids.

When specifying cast-iron pipe it is necessary to give the pipe class, the joint type (whether bell or spigot, flanged, mechanical joint, roll on, or ball and socket), the type of lining (whether cement or bituminuous enamel lining) and the type of exterior coating (whether asphalt varnish or otherwise). For information or assistance in the selection of the proper pipe, joint, and coating, reference is made to the "Handbook of Cast Iron Pipe."

BELL & SPIGOT JOINT



MECHANICAL JOINT



TYPE-2 METROPOLITAN
JOINT FOR
FLEXIBLE JOINT PIPE

TYPICAL PIPE JOINTS

Figure (3-7)

5. **Vitrified-Clay Pipe.**

A. Characteristics. Vitrified-clay pipe is manufactured in sizes 4 to 36 inches in diameter; in some localities pipe 39 to 42 inches in diameter is available. The pipe may be unglazed, salt glazed, or interior ceramic glazed. The laying length of vitrified-clay pipe varies from 3 to 6 feet according to locale, the preference being for longer lengths.

Vitrified-clay pipe is manufactured in standard and extra strength to provide for varying trench depths; in some areas the manufacture of standard strength pipe has been discontinued.

Standard pipe fittings of vitrified clay are available to meet most requirements; special fittings may be supplied on request.

Pipe dimensions and tolerance vary somewhat; therefore, detailed information must be obtained from the local manufacturer and from such manuals as the "Clay Pipe Engineering Manual." When specifying vitrified-clay pipe, the pipe diameter and deviations from standard specification reference should be stated.

The resistance of vitrified-clay pipe to corrosion from most acids gives it an advantage over other pipe materials in handling those wastes which contain high acid concentrations. Laying lengths of 6 feet or less may require more joints than most other materials. The strength of vitrified-clay pipe often necessitates special bedding or concrete cradling to obtain structural stability.

6. **Steel Pipe.**

A. Characteristics. Steel water pipe and sewer pipe have been designed in many ways and according to many different standards. Site locations and installation and operating conditions have largely determined the practices which were followed.

Steel pipe meeting the requirements of the AWWA standard specifications C201 and C202 is satisfactory for pressure sewer mains, underwater river crossings, bridge crossings, and pump station piping if protected by coatings and linings of a type or types to withstand internal and external corrosion.

7. **Special Piping.**

A. Plastic Pipe. Pipe utilizing the following basic synthetic materials generally fall under the category of plastic pipe.

(1) ABS (acrylonitrile-butadiene-styrene).
(2) PVC (polyvinyl chloride).
(3) PE (polyethylene).
(4) styrene-rubber.

Plastic pipe of the type generally considered for use in sewer systems has not had overwhelming acceptance due, in part, to the lack of standards in the industry. However, much progress has been made in the last few years in the production of high quality plastic pipe, particularly for use in small force main construction.

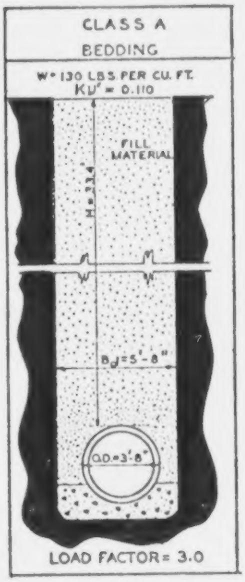
B. Reinforced Resin Pipe – Fiberglass Reinforced Pipe. This category includes those piping materials which are synthetic in nature and laminated in construction. This type of pipe combines the smooth bore typical of plastic pipe and high pipe flexibility and strength.

SEWER CONSTRUCTION

1. **Excavation and Trenching.**

A. Width. Excavation of material from the pipe trench requires a certain degree of skill on the part of the equipment operators. It is important that the backfill load on the installed pipe be within the structural limits of the pipe. Therefore, the trench itself should be dug as close to vertically as possible. The width of the trench should be just enough to permit good jointing procedures and no more. If the trench is wide at the ground surface and narrow at the pipe zone, as in loose sand or round rock excavation, then the backfill load will tend to concentrate on the pipe itself. This can result in crushed piping.

B. Overexcavation. When hard clay or rock is encountered at the required grade for the pipe then it is nearly always advisable to overexcavate and provide a sand or crushed rock bedding for the pipe. Some contractors overexcavate and provide bedding as matter of practice since it almost always saves time. Hand labor is the least productive construction practice and the final grading in the trench must be done by hand. Overexcavation usually reduces the amount of hand labor.



TYPICAL BEDDED PIPE LINE

Figure (3-8)

C. Grade and Alignment. Grade and alignment for the excavation are provided by the engineer in the form of stakes at usually 25-foot intervals and 10 to 20 feet from the center of the trench. Alignment is transferred from the stakes to batter boards which consist of two 2 x 4's driven into the ground on either side of the trench supporting a third 2 x 4 spanning the trench. A nail is driven in the cross-piece and a tight string is drawn between two batter boards. This method, in a narrow trench allows alignment of the pipe to be determined at any intermediate point by dropping a plumb bob from the string.

Grade is precisely determined for the pipe invert or lowest point of the pipe inside diameter. The stakes are marked with reference to this point so that actual grading of the trench requires that the thickness of the pipe be added to the engineer's figure on the "cut stake." Grade may be transferred to the trench by any convenient and accurate method; a level rod, an instrument (level) in the trench on larger jobs, a string line on the batter board set precisely to grade, etc. Each contractor may have a somewhat different way of transferring grade and alignment to the trench. The importance of maintaining smooth and straight grade and alignment cannot be overstressed since careless workmanship always leads to major expenses in rebuilding or repairing sewers.

D. Groundwater. Excessive water in the trench causes real difficulties in sewer construction. Therefore, some means of dewatering the trench must be provided. If the amount of water is not great, it can often be channeled down the trench and pumped out at some downstream point without causing any problem. However, if large amounts of rain or groundwater are encountered, often well points will be sunk into the ground at intervals along side the pipe trench. Such perforated pipes intercept the groundwater before it can enter the trench by pumping from the area around the trench. This practice is common where the sewers are being constructed in fairly open country. However, if there are large buildings or structures nearby, well points should be used with extreme caution since it is not unusual for the rapid draw down of groundwater to result in settlement of nearby structures.

E. Pipe Support. Cushion or bedding under the pipe is most critical since in order for the pipe to withstand the soil pressures from above, it must be supported below. This requires that the bell of each pipe be provided with a depression in the bottom of the trench. Such "bell holes" must be deliberately dug for each bell in order to avoid so-called "bridging" of the pipe, that is, support of the pipe only on the bells. Fracture of the pipe bell is the most common result of bridging.

F. Sheeting and Shoring. When soil conditions are wet or otherwise unstable, some form of bracing may be required to restrict the movement of the soil around the trench and to ensure the safety of the workmen in the trench. The extent of support will depend on the depth of the trench and stability of the soil. If the soil is of such a nature as to require a slight slope to ensure stability, it is often easier to widen the trench at the surface and put a slight slope on the walls of the trench than to construct sheeting or bracing.

(1) intermittent shoring. A skeleton framework of 2 x 12 planks set vertically on each face of the trench and separated by 2 x 4 or 4 x 4 spreaders or trench jacks is termed shoring. The spacing of these "sets" will depend on the depth of the trench and the stability of the soil; but generally, they are spaced at 4 feet to 8 feet on centers. Horizontal plank bracing parallel with the trench face is usually placed behind the vertical planks at the cross support points to add to the wall support.

(2) sheeting or tight sheeting. If the trench walls are unstable and will not support themselves with intermittent shoring, then continuous support must be provided. Such shoring must be of such a structural strength as to resist the thrust of the loose earth of the trench wall. Planks (2" x 12" or 3" x 12") or heavy plywood or tongue-and-groove sheeting is often required for this use. The sheeting, if it is timber planks may be driven into the bottom of the trench to afford stability as deep as possible. In such a case, the sheeting should not be removed below the pipe zone due to the settlement caused by filling the voids where the planks were. Bracing is placed on the inside of the sheeting. The structural requirements of these timbers depends on the width of the trench and the earth load behind the sheeting. Generally 4 x 4 walers and 4 x 4 cross members at 4 feet to 6 feet on center are utilized for narrow trenches and 6-inch to 15-inch pipe.

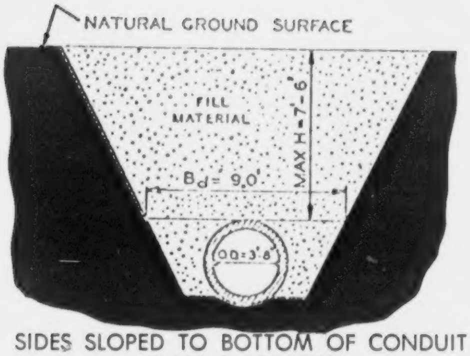
(3) trench shields or coffins. Sometimes it is economical and practical for a contractor to prefabricate a length of tight sheeting, drop this structural frame into the trench and pull it ahead as each short section of trench is opened. This considerably reduces the amount of material necessary for shoring. This method may be used if the trench walls will support themselves long enough for the unit to be pulled into place.

2. **Bedding and Backfill.**

A. Bedding. As previously mentioned, proper bedding of the pipe so that support is provided for the entire length of the pipe barrel is essential for tight sewers. The necessity for special bedding under the pipe to ensure even support is dictated by the native material in the trench. If the material is hard or difficult to hand-excavate or if the material is very wet and affords no support for the pipe, then special material should be provided. Materials vary as to effectiveness in these situations; but normally, crushed rock offers the best characteristics for pipe bedding. A few common bedding materials are:

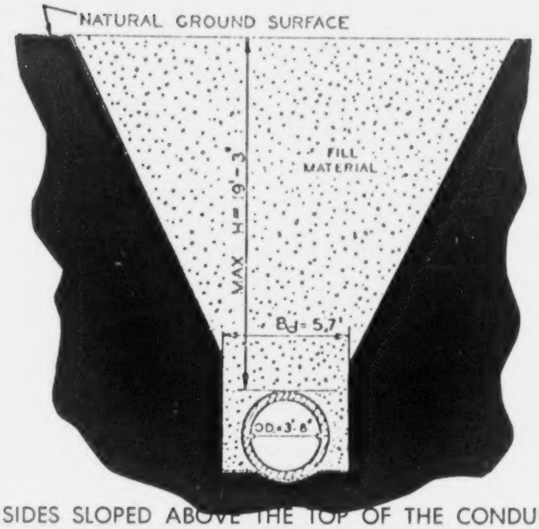
(1) native material. If the material excavated from the trench is predominantly sand or small rock (1 inch or less), then it may be used under the pipe providing it is well tamped prior to placement of the pipe.

(2) sand. Sand bedding is easily worked by hand and allows good flexibility in pipe installation; however, the settlement of sand is greater



SIDES SLOPED TO BOTTOM OF CONDUIT
CLASS-C BEDDING

W= 100 LBS. PER CU. FT. $K_u' = 0.150$



SIDES SLOPED ABOVE THE TOP OF THE CONDUIT
CLASS-C BEDDING

W = 100 LBS. PER CU. FT. $K_u' = 0.150$

Two Typical Methods of Bedding and Backfilling
Figure (3-9)

than either pea gravel or crushed rock and may be uneven depending on natural ground characteristics.

(3) pea gravel. Round rock of about 3/4 inch or less is very workable and is frequently used for pipe bedding based on this characteristic. However, pea gravel is very unstable and responds by movement to the slightest pressure. Therefore, pipe alignment and grade may be affected by the activity of workmen in the trench.

(4) crushed rock. Due to the tendency of crushed rock (1 inch to 1 1/2 inches) to lock into place by intermeshing of fractured surfaces, its use as a pipe bedding material under wet and muddy conditions is most desirable. Also due to this same mechanism, once it is placed and tamped, crushed rock will offer a relatively continuous support for the pipe and is unaffected by minor pressures on the surrounding material.

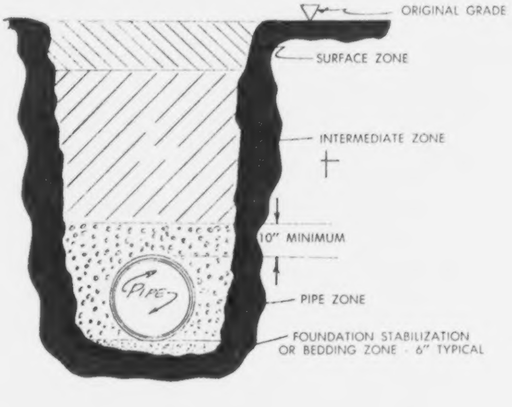
B. Backfill. Probably the most critical operation in sewer construction, with the exception of the jointing practices, is the replacement of material in the sewer trench after installation of the pipe. The backfilling material in an irresponsible manner can result in crushed or fractured pipe, trench settlement problems and an occasional loss of life. Backfilling consists of the replacement of excavated trench material after pipe installation. Procedures and materials of backfill are varied; however, there are certain similarities which can be examined.

(1) materials.

a. native material. Usually material excavated from the trench prior to pipe installation is of such a nature as to be usuable for backfilling of the trench. However, as a rule, precautions are taken, in the form of special backfill material or procedures in the pipe zone to ensure the maximum protection of the pipe from unusual stresses.

b. gravel. In circumstances where native material is not suitable for backfill, gravel may be used with good result. Usually, the maximum permissible size is 4-inch diameter. The material should have fairly even gradation from coarse to fine material. Examples of material suitable for use include clean bank or pit run gravel or crushed rock. In coastal areas beach sand is sometimes used. East of the Cascades, cinders or decomposed granite are often used.

(2) backfill zones. A pipe trench may be considered to have several distinct zones as indicated in the following sketch:



BACKFILL ZONES

Figure (3-10)

Materials used in the bedding zone have been previously discussed. Backfill in the pipe zone must be extremely carefully placed simultaneously on both sides of the pipe to prevent pipe movement. Materials used include reject crusher sand, pea gravel, and crushed rock. Maximum size should be 3/4-inch and the material should be clean and well graded. Compaction is usually done by "slicing" with a hand shovel and with hand operated tamping sticks.

Above the pipe zone, native material or gravel is used as previously discussed. This material is placed by pushing the backfill material down the slope of previously placed material and is placed in layers with mechanical tamping or compaction applied to each layer in the case of backfills which may not be allowed to settle. In the case where backfill settlement can be tolerated, the entire trench is sometimes filled and then settled by water jetting. The trench is then again brought up to grade.

In circumstances where there is no requirement for special surfacing over the sewer trench, the surface zone is essentially the same as the intermediate zone. The final lift should include the piling of dirt slightly higher than the surrounding ground in order to make allowance for future settlement. Where there is pavement of one kind or another or other special surface, the surface zone consists of the preparation of a base at least 12 inches below the surface. Crushed rock is usually employed to provide a stable subgrade material for the surfacing. This begins with large crushed rock (3-inch to 4-inch) provided for stability and ends with smaller rock for smoothness of the final course. Then the surfacing, asphaltic, concrete or other, is applied finishing the backfill operation.

C. Compaction. The ideal conditions of sewer construction would be fulfilled if the dirt that came out of the trench could be returned to the trench in the same position as before except for that displaced by the pipe. Unfortunately this seldom occurs without some mechanical assistance from the contractor. Such water settling or mechanical tamping is termed compaction. Compaction is the attempt to return the soil in the trench to, as nearly as possible its former supporting characteristics. This is accomplished by eliminating the air voids created in the soil by excavation. Water settling, either jetting with pipes inserted into the hill or flooding are acceptable practices and have the advantage of allowing the contractor to completely fill the ditch before compacting. Mechanical tamping must be done for every 6 to 12 inches of fill placed and is therefore time consuming and expensive.

3. Pipe Installation.

A. Pipe Handling. The handling of the pipe itself requires a good deal of care to ensure against cracking and breaking. Unloading from trucks should be done carefully so that the pipe is not dropped or otherwise subjected to unusual stresses. Pipe is designed to withstand at least the normal weight of trench overburden while lying in a horizontal position. It cannot be expected to withstand shock loads or heavy point loadings such as would occur if it were dropped. Therefore, the pipe should be handled carefully and closely inspected before it is lowered into the trench, with particular attention paid to the bell of the pipe where very small "hairline" cracks indicate a dangerous weakness in the individual pipe length.

B. Pipe Placement. Pipe should be strung out ahead of the trenching operation on the opposite side of the ditch to allow equipment free movement. Following completion of excavation, the pipe should be inspected for weaknesses caused in connection with the trenching operations, cleaned, particularly on the ends, lubricated and lowered into the ditch with a sling or other lifting device.

Bell and spigot pipe is usually laid upstream or against the flow of the sewer. The bell end faces upstream regardless of the direction the pipe is laid. Installing the pipe uphill allows any water which might enter the trench to drain downhill and away from the installation operation. Bell holes should be provided during this operation and the bedding under the barrel of the pipe should be smoothed and inspected after laying to ensure even support for the pipe.

If piping installation is discontinued for some reason or at the end of a shift, a stopper should be inserted in the open end of the pipe and the last pipe section should be blocked to prevent creep or loosening of joints during down time.

Any deflection required, as in the case of curved sewers, should be accomplished after the pipe joint is "home", except, of course, in the case of rigid or poured joints.

C. Joints.

(1) clay pipe. Clay pipe joints are of the bell and spigot type, therefore, jointing procedures are determined by the materials used to make the joint tight. Several kinds of material, in different forms, have been or are used in making up clay pipe joints.

a. hot-poured bitumen. A joint made with this material is known generally as a hot-poured joint. The jointing procedure is very much like that used for lead joints on bell and spigot cast iron pipe. The spigot end of the clay pipe is centered in the bell by a ring of calked jute, then melted bituminous material is poured into the joint. The joint is provided with an asbestos-rope snake and gate to permit pouring and to hold the melted material until it cools and sets. The cooled material is then calked into the bell to produce a tight seal.

Disadvantages of bitumen joints include the tendency to become brittle when cold and to flow in warm weather; the difficulty of pouring in cold weather; and the tendency to form steam with extraneous moisture on the pipe surface, causing impairment of surface adhesion or appearance of fissures in the sealing block.

b. cold bitumens. There are three methods of making joints with cold bituminous materials. These procedures do not have the disadvantages of hot-pouring procedures, but the weaknesses of the material, the tendency to crack in cold weather and flow in warm weather, are the same.

Another material used for making clay pipe joints is a plasticized bitumen, in which a softening agent has produced a "butter" that can be troweled into the annular space around the spigot end in the bell. This material will air-set as the "solvent" evaporates.

An extruded ribbon gasket, which may be fortified with fibers or dust, may be used for making joints. The ribbon is wound around the pipe and calked into the bell, without using heat.

In making slip-seal joints, which are also called die cast or premolded joints, complementary precast rings are placed around the spigot and inside the bell. Both rings have a tapered design. When pushed together, they become wedged, causing the joint to become sealed. These rings are generally cast on the pipe at the factory.

c. compression joint. Materials that may be used in making this type of joint are natural or synthetic rubber, e.g., neoprene, or plastics and resins, such as polyvinyl chloride, polyesters, polyurethanes, epoxies, etc.

These materials all have the same advantages: They form flexible joints that allow for maximum deflection; they are resistant to the acids, alkalies, and gases generally found in a sewer; they do not require the use of a spacing material such as jute; they are not subject to shape changes during storage, regardless of weather or temperature; they are resistant to shear loading; when designed for the proper residual compression, they resist leakage, rot penetration, deflection and shear; and they do not require the use of heat in the jointing process. Only one disadvantage is noted; some wastes may attack or tend to dissolve these jointing materials. This effect can easily be avoided by proper selection of materials.

These jointing materials are manufactured in accordance with ASTM Des. C425-60T, which also specifies laboratory test requirements and field performance and acceptance tests. There are three types of joints covered by this ASTM specification.

Type I. The same resilient joint material is used in the bell and on the spigot. Either one of the rings may differ in hardness from the other, but controlled complementary design ensures a positive mating pattern of closure.

Type II. Jointing material on the spigot end may differ in composition from that in the bell, and the hardness and resiliency of one may differ from that of the other, but the controlled complementary design will ensure proper mating and closure.

Type III. The jointing material is a single, true-round, resilient gasket or compression ring. It has a controlled and calculated final shape within the annular space after the joint is made. The gasket or ring may or may not be attached to the spigot or inserted in the bell at the time the pipe is manufactured.

The procedures for making up these compression ring joints are practically the same for all types. Lubricating materials are applied to the pipe end or gasket to offset frictional resistance during the insertion of the spigot into the bell. Pressure is applied to the end of each pipe to force it home and provide the desired joint.

(2) concrete pipe. The jointing procedure for concrete pressure pipe in a force main or pressurized sewer is the same as that for concrete water mains. For gravity sewer lines, the choice of the jointing procedure will depend on the type of joint and jointing material used. Regardless of joint type or material, "construction" should be done in a manner that will ensure watertightness and resistance to root penetration. In preparing project specifications, the design engineer will call for one of four types of joints (bell and spigot, tongue-and-groove, or a collar of concrete or other material) and for one of three types of jointing procedures.

a. cement-mortar bell and spigot joint. In making up this type of joint, the interiors of both the bell and the spigot are cleaned and wetted and a stiff cement-mortar (one part portland cement and two parts clean, fine sand) is applied. The steps involved in making the joint include placing the mortar, fitting the spigot into the bell, forming a mortar bead around the joint inside the pipe, and smoothing the mortar bead.

b. cement-mortar tongue-and-groove. The first step in making this type of joint is the cleaning and wetting of both the tongue-and-groove. Then cement-mortar is carefully placed under the pipe and in the bottom of the joint. The free pipe is inserted into the previously laid section, and the annular space is filled with mortar. During the fitting operation, mortar is squeezed out onto the inner and outer surfaces of the pipe. The inner joint surface is smoothed by a long-handled brush; the outer bead is pointed by trowel.

c. diaper joint on bell and spigot. The procedure for making this type of joint begins with calking jute into the bell. Next the joint is wrapped with a diaper cloth of heavy canvas, the edges of which contain flexible wire, and the wires are tightened. A wet sand-cement grout is then poured into the joint or pumped in through a funnel, using a plunger pump. The diaper is left in place after filling. A tight joint is obtained, even if the joint is made in a wet trench.

d. diaper joint on tongue-and-groove. In making this type of joint, a cheese cloth dipped in portland cement-mortar is wrapped around a conventional tongue-and-groove joint. An 8-inch wide diaper is used to hold a 1/2-inch layer of cement-mortar in place during curing. The band is cured with a covering of moist earth, sand, canvas, or burlap. If backfilling is not done immediately, curing with water for 48 hours is required.

e. concrete collar. A prefabricated reinforced concrete collar is attached to one end of each pipe length at the manufacturing plant. The collar is calked in layers onto the pipe end with sand cement (two parts cement to one part sand) until the collar is full. Approximately half the collar length extends beyond the end of the pipe. Reinforcing in the collar should correspond to reinforcing in the pipe, and the collars should be made by the process used for the pipe.

Collars are at least 7 inches long and range in thickness from 1 3/8 inch for 8-inch pipe diameter, to 5 inches (minimum) for 72-inch pipe. When the pipe joint is made up, the uncollared end of a pipe section is inserted into the collar of a previously laid pipe section, and the joint is sealed by calking cement-mortar (two parts cement to one part sand). After the joint is made up, it is covered with a moist cloth and cured for three days.

f. single rubber ring gasket. The gasket and jointing surfaces must be clean except for the lubricating compound. The rubber gasket is usually slipped onto the spigot end of the joining pipe and the spigot is inserted into the bell. Pressure is applied to the bell end of the joining pipe and the pipe is pushed home. As the pipe reaches the required position, the rubber gasket slips into place and forms a compression seal around the spigot of the pipe. By running the fingers around the inside of the pipe bell, it can be determined if there are any bulges or gaps in the gasket indicating an incomplete joint.

(3) asbestos-cement pipe. The pipe is delivered with a rubber ring and the coupling in place on one end of the pipe, generally termed the "belled end". As in the laying of all bell and spigot pipe, the bell end is laid against the direction of waste water flow. The joint is made in the following manner: The inside of the coupling is cleaned, and the rubber gasket is inserted in the depression inside the open end of the coupling; the "unbelled" end of the pipe is properly lubricated and inserted into the coupling and the pipe is pushed home until the joint is seated properly.

(4) special installation practices.

a. jacking. In this method of installation, pipes are pushed beneath the ground surface by hydraulic jacks. Reinforced concrete pipe sections are commonly used. A working pit is excavated at the point of beginning. This pit should be large enough to provide space for one or two sections of pipe, frames to support them, jacks and the backstop. Guide timbers for pipe support are carefully installed to keep the pipe on the correct line and grade. A jacking head, consisting of bearing blocks, is used to transfer the pressure uniformly from the jacks to the pipe. The jacks must have support at the rear of the jacking pit substantial enough to withstand the thrust during this operation. Timbers, concrete bulkheads, and in some cases, the exposed end of the completed sewer have been utilized for this purpose. Some form of cushioning between the pipe joints distributes the thrust evenly and reduces the likelihood of breakage due to the concentrated pressure. As the pipe progresses, material is excavated from the head of the pipe. Usually the excavation is about one inch larger than the pipe at the top and sides. Jacking is usually done upgrade so that seepage will drain to the working pit. As the work progresses, the line and grade of the lead pipe should be frequently checked.

It is important to keep the pipe moving. When a long stop is made there is the danger that the soil will take a set around the pipe sections making it difficult to start again.

When jacking rubber gasketed pipe, it is essential to use a type of gasketed joint, or to provide a method of cushioning between pipe ends, that will avoid the generation of radial gasket pressures that could cause sockets or grooves to crack.

If excavated material is moved from ahead of the pipe by an auger, the operation is referred to as "boring".

b. casings. When it is necessary to cross under a highway or railroad grade with a sewer line, it is generally required to provide a steel shield around the sewer pipe. This shield or casing is made up of welded steel pipe sections several inches in diameter larger than the sewer pipe bell diameter. The casing is jacked or bored through the earth below the highway or railroad. The pipe is then jointed, supported, and pushed through the casing. Most generally, for smaller pipes, 2 x 4's are wired or clamped to the pipe barrels to raise the bells off the floor of the casing. Then upon completion of installation of the pipe, the casing may be filled with sand, cement grout or concrete. Sometimes the ends only are plugged with concrete to prevent the intrusion of water. However, this is not always sufficient for watertightness due to exfiltration from the sewer and inadequate seal of the concrete around the casing and sewer pipe. Therefore, it is usually better to provide bedding of some type to support the pipe when the wood and bands deteriorate.

4. **Manholes.** The same care exercised for trench excavation and installation and backfill for sewer lines, must be accomplished with manhole construction. Since the manhole is an integral part of the sewer system, it must be as watertight as the sewers.

It is usually necessary to provide bedding gravel below the floor slab of the structure in order to obtain good support for the concrete. The floor slab is probably the most critical part of the manhole construction since if it is not done properly, leakage and failure can occur. The floor supports the incoming piping and provides channels for flow of the sewage. The minimum depth of concrete below the lowest incoming pipe invert should be 6 inches. All parts of the floor slab should be sloped at least one inch per foot to the channel to drain accumulated moisture. The channel itself may be formed in the wet concrete or pipe and can be cast into the wet concrete and the top one-half or one-third of the pipe broken out after the concrete has set-up and bonded to the pipe.

Precast bases are available for manhole construction. These must be plumb and level before risers are grouted in. If precast sections are used for the riser to the ground surface, the first ring must be cast into the floor while the concrete is still wet and workable so that a moisture seal may be provided at the base. Precast manhole sections usually have tongue-and-groove joints so a cement grout or other sealing compound must be applied between each new section. The grout should be applied so that there are no air pockets or gaps in the seal. Sometimes a flexible mastic, epoxy or plastic membrane is used for a watertight seal between sections which will provide some flexibility and will not fracture or separate under the vibration and stress from heavy traffic loads.

Manhole cover frames are adjusted for height by the use of concrete rings and mortar.

Backfilling of the manhole excavation must be done with care so that the incoming pipes are not damaged or the manhole joints broken. Because of the fact that the settlement or flotation of the sewers and the manhole structure will be different, a flexible joint or coupling should be installed as close to the wall of the manhole as possible. Most sewer line failures in new construction occur at the manholes because of inadequate backfilling and different settling rates of the sewer and manhole. In larger sewers, it is advantageous to construct the manhole structure offset from the center of the pipe. This offers the advantages of a smaller diameter entrance tube and observation and maintenance decks in the body of the structure. These are necessarily cast-in-place concrete structures.

If precast manhole sections are utilized, then it is possible to preform the pipe entrances above the base. The rings must be positioned to receive the incoming sewer lines accurately. If pipe entrances must be broken through the manhole wall, as in the case of existing sewers, then the joint between the pipe of the wall must be packed with a relatively dry and preferably nonshrinking grout to seal the joint from the intrusion of groundwater.

The key to successful sewer construction is the maintenance of the watertight integrity of all pipes and structures, both at the time of construction and afterward.

CHAPTER IV

SEWER MAINTENANCE AND CONTROL OF WASTES

GENERAL

Sewers are the conduits or pipes which collect and transport sewage or industrial wastes to the treatment plant. The sewer system will, of course, transport not only the wastes to a plant but will also carry any extraneous material which may find its way into the sewer system either by leakage or other means. Examples of extraneous materials which find their way into sewers include groundwater which infiltrates into the sewer system; sand and gravel, which may enter the system through perforated manholes or badly broken joints; cooling water from industrial processes, which may be piped directly into sewer systems either legally or illegally; and other sources of relatively unpolluted water such as that from roof drains or foundation drains which may be piped to the sewer system either legally or illegally.

Once extraneous material such as this reaches a treatment plant, it is too late to do much about its removal; and the materials, either solid or liquid, must be treated along with the waste flow. Whether this extraneous material is rainwater or some form of toxic waste, it is going to cost money to pump and treat; money which would not have had to be expended if the extraneous material were properly segregated at its point of origin. If the extraneous material is toxic in nature such as might be produced by the waste from a chrome plating works, the possibility exists that the entire treatment process may be completely upset or at least reduced in efficiency by the presence of the extraneous material. Because of the unnecessary expense involved in the pumping and treating of what would be relatively unpolluted water, infiltration and the admission of nonpolluted waste streams such as cooling water and roof drains, should be kept to an absolute minimum in any sewer system. Additionally, the acceptance of toxic wastes or wastes which contain high percentages of greases and oils into a sewer system, should be rigidly controlled.

THE ROLE OF THE SEWER ORDINANCE

Nearly every public body which maintains and operates a sewer system has adopted ordinances controlling the admission of wastes into the system. In most cases, these ordinances provide legal means for the adequate control of admission of wastes into sewer systems. Unfortunately, the various sewer ordinances are not always enforced properly, and it is this lack of enforcement that often results in admission of waste streams into a sewer system which are detrimental to the overall program of treatment. Operators would be well advised to obtain copies of the various ordinances under which the overall system is operated and to become familiar with the various regulations. Assuming that the ordinances provide adequate safeguards, operators should also make local government officials aware, if necessary, of the need for enforcement of the ordinances.

In the event that adequate ordinances are not now provided, operators should bring this fact to the attention of local governmental officials so that such ordinances may be adopted. Copies of model ordinances, which have been successfully used by many cities, are available from either the Water Pollution Control Federation or the Pollution Control Commission.

In summary, operators should be aware that the single, most effective means of controlling admission of wastes, is the adoption and enforcement of stringent ordinances to control admission of wastes into sewer systems.

SEWER MAINTENANCE

1. **Infiltration.** Infiltration may be defined as the leakage of groundwater into sewer systems. Infiltration is a universal problem since it is probable that no sewer system is entirely water-tight. Even a very small leak can contribute a considerable amount of water into a sewer system, since the leaks generally occur 24 hours a day on a more or less continuous basis depending upon groundwater levels in the system. Another way to look at the infiltration problem is to compare the total volume of water which leaks into the sewer system with the total volume of waste which would occur if leakage was not present. In general, operators might expect to receive approximately 100 gallons per day of waste water for each person that is connected to a sewer system. Thus it may be seen that for approximately every 100 gallons of water which leak into a sewer system daily, the capacity of the system as well as the treatment plant to adequately perform its intended job is reduced by one person. Infiltration can enter a sewer system in a number of ways, including through perforated manhole covers, leaking manholes, leaking joints and cracked pipe, unplugged wyes or tees and broken house connections. All of the above mentioned will contribute a considerable amount of water to

the system. Most of them will also contribute a considerable amount of sand and grit.

2. **Inspection.** A good sewer maintenance program requires that periodic maintenance inspections of all sewers in the system be made. Maintenance inspections can be made in a number of ways. A number of inspection methods which have been successfully used are herein described; all of the methods described are good; however, each has certain advantages and disadvantages which depend upon local conditions.

A. Smoke Testing. The smoke test is an extremely easy and rapid test to perform. The equipment required is fairly inexpensive, and the cost for each individual test is likewise small. The required equipment is as follows:

One gas engine powered blower of approximately 1,500 cfm capacity.

One 3-foot square sheet of 3/4-inch exterior plywood.

One 3-foot square piece of soft sponge rubber (used as a seal on the bottom of the plywood panel).

One piece of 8-inch flexible air duct provided with clamps at each end.

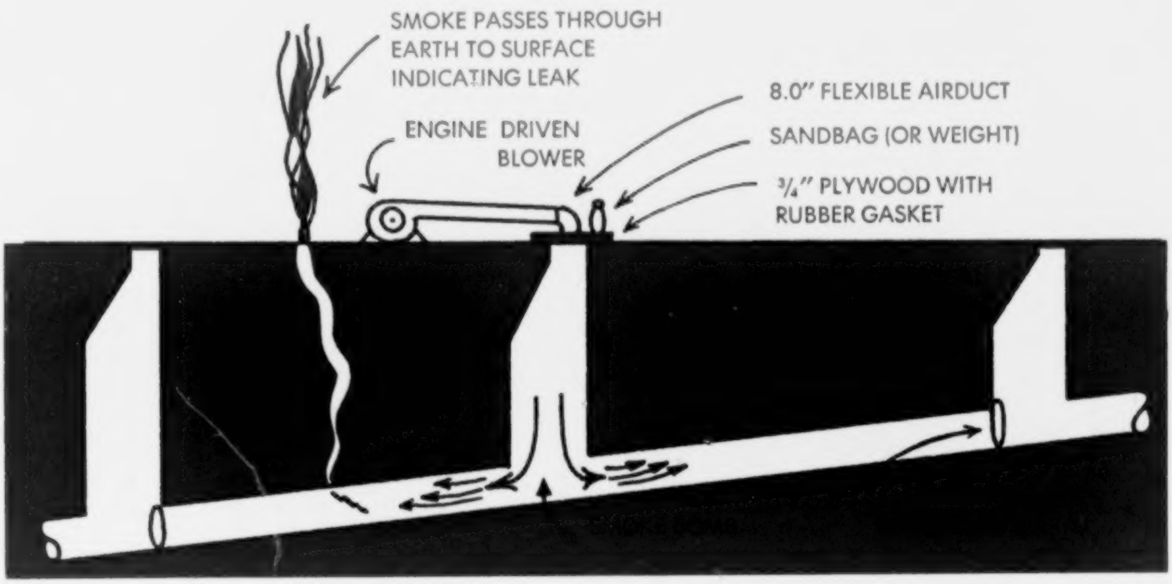
One 8-inch elbow to go through the plywood.

Smoke bombs of 3- to 5-minute burning time as required.

Sand bags as required.

Sewer pipe plugs to stop the air flow in the line at the upper and lower manholes.

Figure 4-1 illustrates the method of performing the test. If there are any breaks in the pipe or poorly constructed joints, smoke will be forced out of the breaks by the air pressure created by the portable fan. This smoke will seep out and come up through the ground or through minor cracks in pavement if the sewer line underlays a paved street. It must be remembered that the smoke will not necessarily exist at the ground surface in the same location as a break in the sewer pipe. In this respect the smoke test merely indicates whether or not the line is broken but does not pinpoint the location of the break. The smoke test cannot be used in sewer lines which are surcharged with water because the smoke will not pass up through water. The smoke test is likewise not effective if the groundwater table is significantly above the sewer line. The smoke test is particularly effective in finding illegal connection to sewer systems such as roof drains and parking lot drains. It also is very effective in locating untrapped vents in plumbing systems. Unplugged wyes, tees and broken house connections as well as basement footing drains will also show up quite readily when subjected to the smoke test.


SMOKE PASSES THROUGH EARTH TO SURFACE INDICATING LEAK
ENGINE DRIVEN BLOWER
8.0" FLEXIBLE AIRDUCT
SANDBAG (OR WEIGHT)
3/4" PLYWOOD WITH RUBBER GASKET
SMOKE BOMB

Method of Smoke Testing Sewers

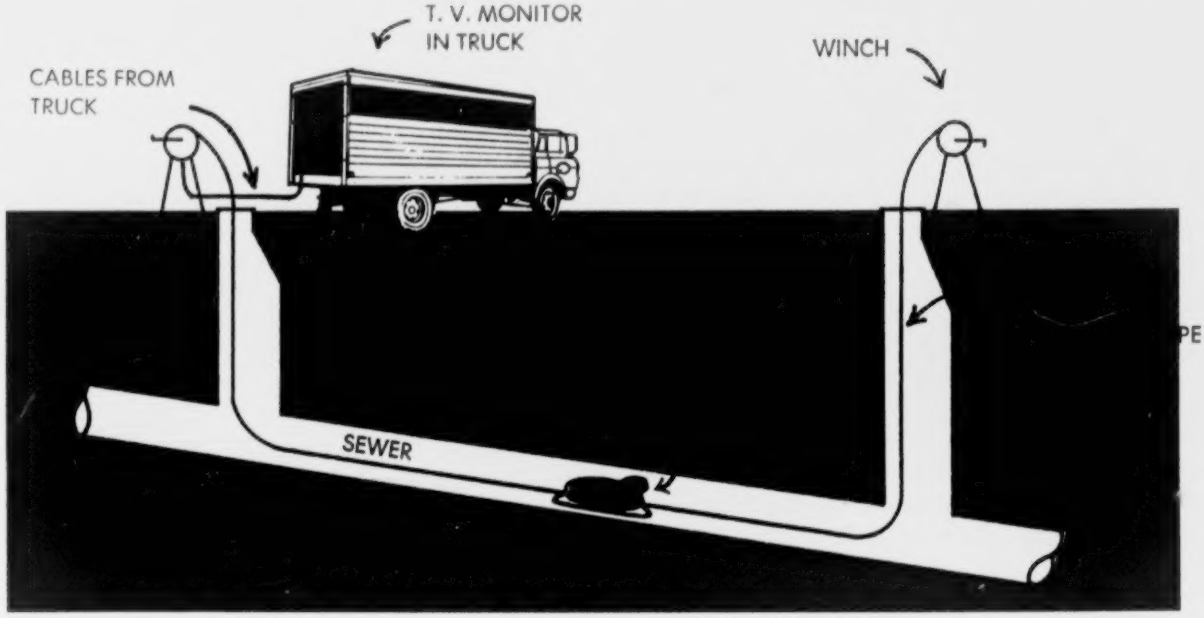
Figure (4-1)

Local fire departments as well as the owners of all property connected to a sewer system in the vicinity of a proposed test should be notified of the testing procedure well in advance of the start of the test. This notification is necessary since, quite often, water contained in plumbing traps evaporates if the fixtures are not often used. If untrapped or trapped fixtures in which the liquid seal has evaporated, are subjected to a smoke test, smoke can be forced up through the entire vent system of the residence or business building thus possibly filling the rooms with smoke. Such cases have been known to happen, and while no actual damage is suffered by the property owner due to the smoke the experience for a property owner is, to say the least, unnerving.

B. Television Inspection. Television inspection is a very satisfactory way to inspect sewer lines, and if properly done will yield more information about the condition of a sewer line than any other method. Unfortunately, the procedure is quite time consuming; and the equipment used is very expensive. Before television inspection of a sewer line can be properly done, it is necessary to thoroughly clean the sewer. It is also necessary that the depth of flow of sewage in the sewer line be less than about 3 or 4 inches depending on the type of television camera used so that the camera lens is not submerged in sewage. The television camera will accurately show such things as broken pipe sections, broken pipe barrels, rubber rings which have dropped into the line, roots protruding into the line from either poorly constructed house connections, or bad joints or broken places in the line, joints which have shifted or come apart due to improper backfilling or settlement of the line, and house connections which protrude too far into the line. Because of the rather complete information concerning the condition of any sewer line, television inspection is an excellent way to determine what type of repairs may be most economical for any given situation. The television inspection system is quite often used in conjunction with internal sewer sealing methods which will be described in more detail in a later section of this chapter.

Figure 4-2 indicates the method used in television inspection. The television monitoring screen is usually mounted in a panel truck or trailer, and this screen displays continuously the condition of the line as the television camera is moved through the sewer line. A measuring tape is pulled through the sewer with the camera so that the location of any defects which are noted can be recorded for future attention. It is possible to take pictures of the television monitoring screen of any trouble spots which are noted. A Polaroid camera works quite well for this because the photo may be developed immediately and the camera can be repositioned if necessary in the event that it is necessary to take additional pictures.

The original cash outlay for television testing equipment is extremely large. However, large cities



Method of Television Inspection

Figure (4-2)

have found that the use of the equipment represents a definite overall savings in their sewer maintenance program. Many smaller cities engage the services of sewer inspection and repair specialists to perform testing of lines which are suspected to be in bad shape. In some other instances, cities may rent all required equipment utilizing their own personnel for operation.

C. Air Testing. Sewers may be tested for leakage by a method known as air testing. In this method, sewers are completely drained of all water and plugged tightly at each end of a test section. Commonly used plugs include rubber tires mounted on steel rims of a size which may be inserted into a sewer line and which, when expanded by applying air pressure to the tire, will provide an air-tight seal around the pipe. Air under pressure is then admitted to the test section, and after waiting a period of time for the air pressure to stabilize due to changes in temperature, the loss of air pressure is measured by means of a pressure gauge. The air testing method is not commonly used for sewers which have been in use for some time; however, it is a very popular method for testing of new sewers before they are placed into operation. The air test method cannot be used on sections of line which have house connections unless each individual house connection is blocked. It is for this reason that the test is not widely used for existing lines. A recommended procedure for using the air test method is contained in the appendix at the end of this manual.

3. **Vector Control.** Controlling rat populations in sewer systems can be quite a problem. Sewer systems spread throughout every corner of a community and provide a relatively safe, easy route to travel throughout an entire city for rats and other rodents.

One easy way for maintenance crews to deal with rodent problems is to make up and hang in various manholes, a poison bait. This can be done quite easily by using any commercially available rat poison such as DeCon and mixing it with paraffin and then hanging the cubes thus formed in manholes. An easy procedure is as follows: Cut quart milk cartons off about 3 inches above the bottom and pour a mixture of melted paraffin and DeCon into the milk carton forms. When the mixture is dry, remove the paper form and insert a wire through the cube of poison of the required length so that the bait can hang in a manhole slightly above the crown of the pipe. The wire may be easily inserted by heating the end of the wire and then forcing it into the paraffin. The wire hanger should extend completely through the paraffin block, and a loop should be made at the lower end to prevent the poison block from stripping off the wire. Records should be kept of all manholes thus treated including the date that poison was first used and any other pertinent information. This method will probably not be effective in controlling extremeley heavy infestations of rodents; and it should be considered more as a preventive maintenance program rather than a complete extermination program.

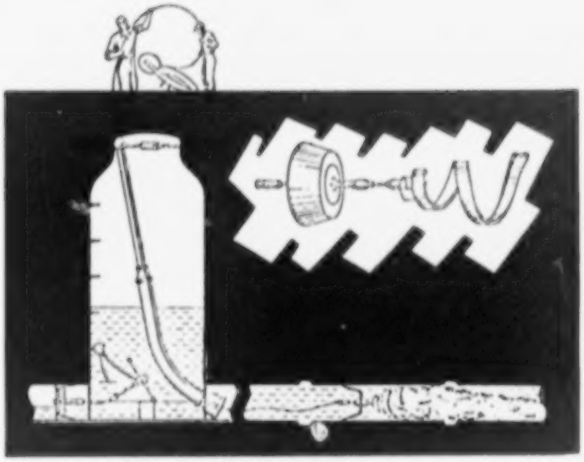
In the event that extremely heavy infestations of rodents are found to be present, it is best to engage the services of reputable pest control specialists, since many of the most effective rat poisons require State licensing for their use.

4. **Sewer Cleaning.** Periodic cleaning of sewer lines is essential to proper operation of any sewer system. There are many ways to clean sewer lines including flushing, rodding, balling, and bucketing. Of these methods, flushing is probably the easiest and least expensive. Flushing, however, will not be effective if extremely heavy deposits are present or if a line is completely plugged. To flush a line, it is advisable to use a tank truck or as a minimum, a fire hydrant. The effectiveness of flushing depends on the velocity of flow which can be created. The velocity of flow, in turn, depends upon the volume of water which is introduced into a sewer. Accordingly, for flushing to be effective, it is always necessary to introduce water into a manhole as fast as is possible in order to assure that cleansing velocities will be obtained.

Maintenance crews should remember that any material which is thus flushed from a sewer system may eventually deposit again in downstream sections of the sewer system. Maintenance crews should also remember that flushing may result in temporary hydraulic and organic overloads at the treatment plant. Accordingly, treatment plant operators should always be advised if any considerable amount of flushing is to be undertaken.

Flushing is usually most effective on dead end lines which have very few connections and which tend to plug periodically. For this reason, it is advisable to keep records of trouble spots in a system which may require periodic flushing. In this manner, a regular flushing program may be set up thus avoiding periodic complaints from residences located on such lines.

Rodding of sewers is a quite effective method for removal of tree roots and obstructions which may be slowing or completely blocking sewage flow. A number of rodding machines are available including hand operated sewer rodders for small lines as well as larger, power-driven machines for larger lines.



Flexible Sewer Rod on Tape
For Roding Sewer Lines

Figure (4-3)

Another effective method for cleaning sewers is balling. In this method, a special ball is placed in a sewer line and forced down the pipe by a head of water built up behind it. This can be accomplished by filling or at least partially filling an upstream manhole. The higher the head of water behind the ball, the more efficient the operation will be. If this method is used, precautions must be taken in order to assure that the head of water built up behind a sewer ball will not cause overflow through basement drain systems which may be lower than the head of water used. Cables should always be attached to the ball so that it may be withdrawn in the event that it encounters a house connection which may protrude too far into a sewer line or a broken joint thus making passage of the ball downstream impossible.

Probably the most effective method of cleaning grit or large chunks of material from a sewer is the bucketing method. This consists of dragging a special steel bucket through a sewer by means of a winch and cable. The bucket then scoops up sand and large objects in the sewer. The material thus removed can be placed in dump trucks and hauled away for disposal. Two winches are used in this method–one to pull the bucket forward for the cleaning operation and the other winch to pull the bucket back down the line. Special bucketing machines are available, some of which are equipped to automatically raise the bucket up a manhole for easy discharge of collected materials. The bucketing method should not be used where house connection joints protrude into a line or where very rough joints or broken pipe may be encountered since the use of a bucket under these circumstances may do more harm than good.

A maintenance routine should be set up to check on all chronic trouble spots which may exist in any sewer system. Such things as a periodic flushing schedule, removal of tree roots where these become a problem, and periodic checking of manhole rings and covers should be included in any maintenance program. Maintenance crews should also be on the alert for potential problems which might occur such as water-tight manhole covers which have become loosened or broken and poor surface drainage conditions which might cause overflow of surface water into a sewer system through perforated manhole covers. Perforated manhole covers are widely used in the Pacific Northwest; however, there is some disagreement among designers as to whether or not perforated manhole covers actually serve any useful purpose. The purpose of perforations in manhole covers is, of course, to allow escape of noxious gases which may be created in sewer systems. However, the perforations also provide an excellent means of access for sand and grit to enter a sewer system. In many cases, particularly where graveled streets are present, cities have plugged the manhole perforations in order to minimize the amount of grit which enters sewer systems.

5. **Sewer Location Maps.** The importance of up-to-date sewer maps for any sewer system whether large or small, cannot be overemphasized. Responsible officials should make every effort to keep sewer location maps up-to-date and correct in all respects. It is usual practice to indicate on the maps the location of each connection to the sewer system as well as profile information. At the cost of very little time and effort expended on keeping such maps up-to-date, a tremendous amount of hard labor spent at digging for suspected house connections, manhole locations, and sewer locations can be avoided. It is wise to have a liaison system set up with officials responsible for issuance of building permits so that information concerning new sewer connections can be immediately placed on sewer maps. If sewer permits for connection to sewer systems are required, the need for such liaison may be eliminated.

6. **Sewer Repairs.** Repairs to sewers and sewer systems include maintenance of streets and adjustment of manhole rings and covers as well as actual repair of manholes and sewer pipes. Leaking manholes can usually be repaired from the inside of the manhole, utilizing special hydraulic cements which are commercially available and which will stop leaks which may exist even under considerable hydraulic pressure from the outside of the manhole. Broken or badly cracked sewer pipes, unless they are of sufficient diameter to allow working from

the inside, must usually be dug up and replaced. Recently, systems have become more popular which allow in-place sealing of sewer lines. These in-place systems may be effective where the structural condition of the pipe to be repaired is not particularly bad, and it is only necessary to control leakage through joints.

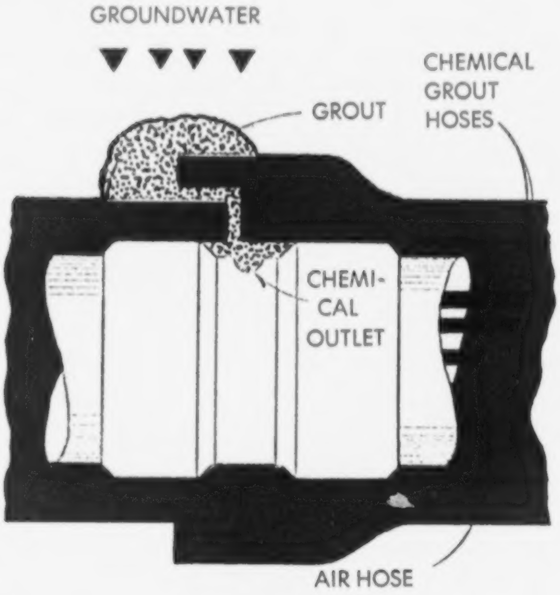


Figure 4-4
Pressure Grouting Apparatus

There are several in-place sealing methods in present use which involve either liquid chemical sealants or slurries or chemical grouts applied under pressure from inside the pipe or jetted into the pipe zone from the outside. In the last few years, the use of chemical grouts for soil stabilization and sewer leakage correction has become widely used. One particular method which has enjoyed considerable success, is employed by the Gelco Grouting Service of Salem, Oregon. Their method utilizes a packer which consists of two rubber pneumatic rings mounted on a hollow section of pipe. The packer is illustrated in Figure 4-4. The pressure in the rings is controlled from the surface, thus allowing short sections of a sewer to be treated at a time and eliminating the need for plugging the side sewers before treatment. Also, the hollow center of the packer allows a flow of up to one-third of the sewer capacity to pass through during the treatment processes. Similar jointing devices are also used by other firms.

A television camera is pulled through the line and relays detailed information of pipe conditions as previously described and locates defective areas where sealing is required. The packer is then moved through the line and positioned in view of the television camera. The ends of the packer are expanded, isolating the point of leakage. Into this isolated area, through hose lines leading from a vehicle above ground, liquid plastic compounds are pumped with pressures in excess of groundwater pressures. These fluid chemicals pass through the leakage point sealing the path of leakage in the adjacent soil area. The chemicals "set up" into a semirigid solid in less than one minute. The packer is then contracted and the results of the sealing inspected by the television camera.

The approximate cost of this type of sewer sealing can be of from 2 to 4 dollars per foot depending upon the size and location of the sewer. Experiences at Walla Walla, Seattle, and in the Portland, Oregon area have been very satisfactory with this particular process.

The major disadvantage of this type of system is that the side sewers are not treated. However, if the side sewers are found to be a major contributing factor to the infiltration in a sewer system, they can be treated by other methods. The first of these methods is to jet a grout pipe down from the ground surface and to apply pressure grout around the side sewer. The second method is to fill the side sewer with a chemical grout and allow this chemical to exfiltrate through breaks in the pipe and subsequently solidify and seal the breaks.

7. **Safety.** "Safety first" is a creed which should be practiced 100 percent of the time when working around sewer lines. Safety equipment must not only be provided but used and used properly. A few of the items which would be necessary while working on a sewer line in a street are as follows: barricades, flashing lights, flags, and sometimes a flagman to warn motorists that someone is working in the street. Gas testers, gas masks, and portable oxygen tanks that strap on the back should be available. A portable fan or blower to pump fresh air into a sewer line should also be available and in use whenever personnel are working in manholes. Don't position the blower fan intake near any motor exhaust. Above all else, never go into a manhole or sewer line alone. Always have someone on top to keep an eye on you. Know traffic regulations. Report street closures or slow traffic to the police department.

CHAPTER V

CHARACTERISTICS OF SEWAGE AND OTHER WASTES

INTRODUCTION

Sewage is the used water originating from human wastes, animal wastes, storm flows, groundwater infiltration and industrial wastes. It comes from buildings, residences, institutions and streets or land. The water-carried wastes contain sand, grit, dirt, organic material, bacteria and chemicals which give it characteristics that are usually offensive to the people who are responsible for its origination. These same people want this offensive material to be sent off where it no longer bothers them. Therefore, the sewage treatment plant has usually been relegated to the area behind the bushes away from inhabited areas. It is only in recent years that sewage treatment plants have been partially acceptable to residents who crowded in around them. This partial acceptance of sewage treatment has also made it necessary for operators to operate plants so that odors and unsightly materials are kept to an absolute minimum.

The quantities of domestic and municipal sewage vary considerably depending on the type of wastes. A residential area with tightly constructed sewers, separate storm drains and no industrial waste may be as low as 40 gallons per person per day. An average area with reasonably good conditions will produce about 100 gallons per capita per day. Unfortunately, many sewerage systems which have not exluded storm waters leak badly during high groundwater conditions. They also may contain industrial or other high strength and high volume wastes. Quantities may well exceed 200-300 gallons per capita per day. Industrial waste quantities may be high and may be strong, toxic or hard to treat.

The quality of sewage is judged by appearance, odor, color, and laboratory tests designed to show its physical, chemical and biological characteristics. The impurities in sewage constitute only about one percent (1%) by weight of the sewage. This one percent must be removed before the used water can again be of a quality acceptable for a receiving stream.

PHYSICAL CHARACTERISTICS

Solids in wastes can generally be divided into inorganic and organic solids. Sewage in its travel from the point of discharge to the treatment plant picks up sand and grit which are inorganic and are practically inert. These solids are heavy and can be removed readily by slowing down the flow so that the particles will settle.

Organic solids such as feces and garbage are more complex. Portions of the material will settle and other portions will rise to the surface. The remainder stays in solution and has to be removed by biological or chemical means. The following definitions describe the various types of solids:

1. **Organic Solids.** Organic solids are generally of animal or vegetable origin, including the waste products of animal and vegetable life, dead animal matter, plant tissue or organisms, but may include synthetic organic compounds. They are substances which contain carbon, hydrogen and oxygen, some of which may be combined with nitrogen, sulphur or phosphorus. The principal groups are proteins, carbohydrates and fats together with the products of their decomposition. They are subject to decay or decomposition through the activity of bacteria and other living organisms and are combustible; that is, they can be burned.

2. **Inorganic Solids.** Inorganic solids are those substances which are inert and not subject to decay. Exceptions to this characteristic are certain mineral compounds or salts, such as sulfates, which under certain conditions can be broken down to simpler substances. Inorganic solids are frequently designated as mineral substances and include sand, gravel, silt and the mineral salts in the water supply which produce the hardness and mineral content of the water. In general, they are noncombustible.

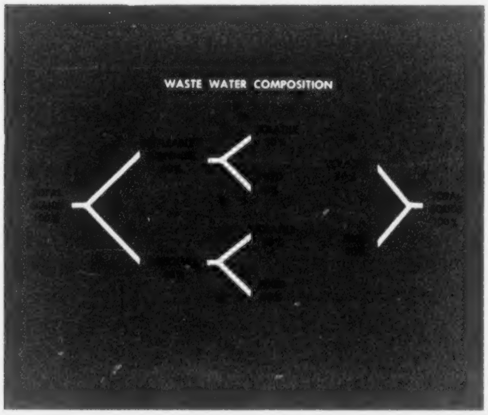
The amount of these solids, both organic and inorganic, in sewage, imparts to it what is frequently termed its **strength**. Actually the concentration of the organic solids and their capacity to undergo decay or decomposition is the principal part of this strength. The greater the concentration of organic solids, the stronger the sewage. A **strong sewage** can be defined as one containing a large amount of solids, particularly organic solids. A **weak sewage** is one containing only a small amount of organic solids.

As already noted, solids can be grouped depending on their physical state as suspended solids, colloidal solids and dissolved solids, each of which may include both organic and inorganic solids.

3. **Suspended Solids.** Suspended solids are those which are visible and in suspension in the water. They are the solids which can be removed from the sewage by physical or mechanical means, such as sedimentation or filtration. They include the larger particles and consist of sand, grit, clay, fecal solids, paper, sticks of wood, particles of food and garbage, and similar materials. They are about 70 percent organic solids and 30 percent inorganic solids,

the latter being principally sand and grit.

Suspended solids are divided into two parts – settleable solids and colloidal solids:



WASTEWATER COMPOSITION

Figure (5-1)

4. **Settleable Solids.** Settleable solids are that portion of the suspended solids which are of sufficient size and weight to settle in a given period of time, usually one hour. As used in this manual, they are those which will settle in an Imhoff cone in one hour. They are usually reported as milliliters of solids per liter of sewage and are 75 percent organic and 25 percent inorganic.

5. **Colloidal Suspended Solids.** Colloidal suspended solids are somewhat loosely defined as the difference between the total suspended solids and the settleable solids. There is at present no simple or standard laboratory test to specifically determine colloidal matter. Some will settle out if the quiescent period in the Imhoff cone test is longer than one hour, but most will remain in suspension over long periods of several days or more. They constitute that portion of the total suspended solids (about 40 percent) which are not readily removed by physical or mechanical treatment facilities. In composition they are about two-thirds organic and one-third inorganic, are subject to rapid decay, and are an important factor in the treatment and disposal of sewage.

6. **Dissolved Solids.** The term "dissolved solids" as commonly used in discussing sewage is not technically correct. All of these solids are not in true solution but they include some solids in the colloidal state. Of the total dissolved solids, about 90 percent are in true solution and about 10 percent colloidal. Dissolved solids are about 40 percent organic and 60 percent inorganic. The colloidal portion is higher in percent organic matter than the solids in true solution as the latter includes all of the mineral salts in the water supply.

7. **Total Solids.** Total solids, as the term implies, includes all of the solid constituents of sewage. They are the total of the organic and inorganic solids or the total of the suspended and dissolved solids. In an average domestic sewage they are about half organic and half inorganic, and about two-thirds in solution and one-third in suspension. It is the organic half of the solids subject to decay, that constitute the main problem in sewage treatment.

The color of sewage is generally gray, similar to dishwater in its fresh state. It may turn completely black if allowed to become septic. Soil and other materials from land runoff may affect the color and make it gray-brown to brown. Industrial wastes can impart any color to the sewage depending on the type of waste. It is sometimes startling to see the color change from brilliant red to azure blue in the course of a few minutes in the vicinity of a textile mill. It is spectacular to watch a flow of several million gallons per day of waste colored blood-red by beets from a cannery or by blood from a meat processing plant. The new waterproof glues impart color ranging from brown to purple to bright red. These and other colored wastes can indicate the freshness or septic nature of sewage and the source of the waste.

Typical domestic sewage does not impart an offensive odor when fresh. Usually the most noticeable odor is that of soapy dishwater. When the sewage becomes septic, it may be extremely odorous from the hydrogen sulfide and other gases that are given off. Industrial wastes of various sorts have characteristic odors that are associated with the products or waste portions produced. Odors may be indicators that tell the freshness of the sewage, the source of the wastes and the possible problems to be expected in treatments.

Temperature of sewage is generally higher than that of air because household wastes carry warm water. Industrial wastes may vary from cold to hot wastes depending on the processes concerned. The normally warm temperatures speed up bacterial action and are therefore not detrimental to treatment.

Aesthetic considerations are probably the most important of the physical characteristics of sewage. People see the floating debris and recognizable materials in sewage. They object to any of this recognizable material coming through the plants and showing up in a water course. Because of the appearance, changes in color and the changes in odors, sewage must be conducted rapidly and without leakage to and through treatment works so that the effluents are clean and inoffensive to the public.

CHEMICAL CHARACTERISTICS

Fresh sewage is a relatively neutral waste with a pH of about 7.0. Septic sewage is in the acid range with a pH usually below 6.0. Alkaline wastes with pH above 7.0 are indicative of some unusual condition. Industrial wastes in the sewage can fluctuate from acid to alkaline depending on the source of the waste and its reaction with the sewage after mixing.

Septic sewage gives off hydrogen sulfide and other gases which can be corrosive to both metals and concrete. Because sewers do not ordinarily run full, the air space above the sewage can accumulate gases which will attack concrete and cause it to deteriorate. Metal ladders in manholes have been corroded by the sewer gases. If septicity is allowed for a long period of time, combustible gases also form and explosions can easily result. It is beneficial to keep the sewers flowing and get the sewage to the plant as soon as possible to avoid the odorous, unsightly, corrosive and dangerous conditions that are associated with septic sewage.

Grease and oil are perhaps the messiest materials that occur in sewage. Wherever possible, it is preferable to remove these undesirable materials before they reach the sewers. Service stations are nearly always equipped with grease traps designed to hold the greases and oils accumulated in the operation. Although, many service station attendants fail to have the tanks pumped. Detection and correction of such situations becomes imperative. Meat processing plants provide another example of a source of grease that must be controlled. The grease that does reach the plant is removed by skimming and can be disposed of either by hauling it to a rendering plant or by putting it into the digester for breakdown.

In past years, streams, lakes and impoundments have been showing increasing growths of algae and other aquatic growths. Several cases of extreme growths that cause nuisances have been pinpointed to sewage discharges. The chemicals involved are phosphates, nitrates and trace elements. These are so-called nutrients. Sewage contains those nutrients and trace elements along with vitamins and other organic materials that are necessary for growth. The trend at the present time is toward finding methods for economically removing the growth factors before sewage is discharged into a water course. This is the basis for the "tertiary treatment" movement which has become popular in the last few years.

With regard to dissolved oxygen content, sewage can vary from one in which oxygen is plentiful (aerobic system) through one in which oxygen is a part time visitor (facultative system) to one which does not have any oxygen available (anaerobic system). Considering the source of sewage and the methods by which it is treated, almost any type of organism may be present. Most of these organisms work toward the breakdown of the waste to a less harmful type of material. These include the bacteria which under aerobic or facultative conditions decrease the biochemical oxygen demand of the waste.

Because much of the sewage flow does originate from humans, pathogenic (disease producing) organisms can also be a problem. Along with these organisms are large quantities of the coliform group of organisms which are typical inhabitants of the intestinal tract of warm-blooded animals. The coliform group is used for indication of the possible presence of pathogenic organisms in the MPN (Most Probable Number of coliform organisms per 100 milliliters) test. Disease possibilities cannot be overemphasized. Table 5-3 illustrates a few of the many water-borne diseases which adequate sewage treatment can help to control.

Toxic chemicals can be dangerous to man and to the organisms in the sewage treatment plant. Imagine, for example, going into a pump station full of the fumes from gasoline or carbon tetrachloride. Think of the consequences of investigating the smell of kerosene and finding that someone had dumped pesticides into the sewers. Even chlorine, which is useful in the plant, can be extremely dangerous in the depths of a sewer or a wet well. Furthermore a particular chemical may not be toxic to man's environment, but may destroy the biological life which man depends upon for the breakdown of wastes. Heavy metals, such as hexavalent chromium, are in this class. They affect man and animals if they are ingested, but can be handled without harmful results. If, however, they are present in excess in the organism's environment and are ingested, the organisms may be killed, causing sewage to pass through the plant untreated. These undesirable chemicals must be traced to their source and treated at that point where the flows are small and organisms do not exist.

BIOLOGICAL CHARACTERISTICS

There will not be any attempt at this point to describe in detail all the various organisms that may be found in sewage and sewage treatment processes. In general, organisms found in treatment works include bacteria, fungi, yeasts, molds, protozoans, rotifers, crustaceans, and algae. A general classification and scientific naming of organisms follows.

The living world is divided into two great kingdoms, the Animal Kingdom and the Plant Kingdom. Closely related animals share certain characteristics not found in other animals, and the same is true of plants. These distinguishing and relating characteristics form the basis for classifying all animals into main groups named phyla and all plants into similar groups designated as phyla or, in some classifications, divisions. Each Phylum or Division is broken down into small subgroups of more closely related organisms and this process is repeated until in the smallest unit of classification only minor variations exist between individual cells. The plan includes these subgroups:

- Kingdom
  - Phylum (Division)
    - Class
      - Order
        - Family
          - Tribe
            - Genus
              - Species

Minor variations are always present in a species, and no two individuals are exactly alike. If some members of a species share one or more of these variations they may be considered a subspecies, type, variety or strain of that species.

In practice an organism is named according to the genus and species to which it belongs, i.e., according to the system of binomial nomenclature (the two-name system). Thus man has the scientific name Homo sapiens; man belongs to the genus Homo and the species sapiens. The generic name is capitalized while the species name is begun with a small letter. Scientific names of organisms are commonly designated by underscoring or italics.

Classifications are arbitrary schemes and there is some diversity of opinion among authorities as to proper grouping and naming of plants either by the discovery of new organisms or the description of new relationships between organisms. For the purpose of this manual, taxonomy (the science of classification), is not important. A classification of plants is presented to acquaint the student with the position in the plant kingdom of microorganisms belonging to the Algae and the Fungi. One of the simplest classifications of animals serves to relate microorganisms known as Protozoa to the rest of the animal kingdom. Tables 5–1 and 5–2 show the classification scheme.

TABLE 5-1

CLASSIFICATION OF THE PLANT KINGDOM

Phylum Algae	Chlorophyll containing thallophytes.* Includes microscopic green plants and the seaweeds.
Class Chlorophyceae	Grass-green algae
Class Euglenophyceae	Euglenoid algae
Class Myxophyceae	Blue-green algae
Class Phaeophyceae	Brown algae
Class Xanthophyceae	Yellow-green algae
Class Chrysophyceae	Golden-brown algae
Class Bacillariophyceae	Diatoms
Class Dinophyceae	Dinophycean algae
Class Rhodophyceae	Red algae
Phylum Fungi	Thallophytes possessing no chlorophyll. Includes mushrooms, toadstools and other fleshy fungi as well as molds, yeasts, and bacteria.
Class Schizomycetes	Bacteria
Class Myxomycetes	Slime molds
Class Phycomycetes	Alga-like fungi
Class Ascomycetes	Sac fungi
Class Basidiomycetes	Club fungi
Class Dueteromycetes	Imperfect fungi
Phylum Bryophyta	Mosses, liverworts and hornworts
Phylum Tracheophyta	Vascular plants including ferns, horsetails, ground pines and seed plants (cone-bearing evergreens and flowering plants).

*Algae and fungi are commonly known as thallophytes or "thallus plants." A thallus is a simple plant body lacking true roots, stems and leaves. Thallophytes have unicellular reproductive structures.

TABLE 5-2

CLASSIFICATION OF THE ANIMAL KINGDOM

Phylum Protozoa	One-celled animals
Phylum Porifera	Sponges
Phylum Coelenterata	Hydra, jellyfish, sea anemones, corals
Phylum Ctenophora	Sea walnuts or comb-jellies
Phylum Platyhelminthes	Flatworms: Planaria, flukes, tapeworms
Phylum Nemathelminthes	Round worms: vinegar "eel", hookworm, Trichinella, Ascaris

TABLE 5-2 (Cont.)

Phylum Rotifera	Rotifers, microscopic fresh-water "wheel animalicules"
Phylum Bryozoa	"Moss animals" in colonies encrusting plants, rocks and animal shells
Phylum Brachiopoda	Bivalved "lamp shell" animals
Phylum Echinodermata	Spiny-skinned animals: starfish, brittle stars, sea urchins, sea cucumbers, sea lillies
Phylum Mollusca	Chitons, snails, slugs, squid, octopus, oyster, clams
Phylum Annelida	Segmented worms: clam worm, earthworm, leeches
Phylum Arthropoda	Joint-footed animals: crabs, lobsters, centipedes, millipedes, insects, scorpions, spiders, ticks, mites
Phylum Chordata	Animals with a "back string" or notochord
Subphylum Hemichorda	Balanoglussus
Subphylum Tunicata	Sea Squirts
Subphylum Cephalochorda	Amphioxus
Subphylum Vertebrata	Animals with a vertebral column or backbone
Class Cyclostomata	Lamprey, hag fishes
Class Elasmobranchii	Shark, dogfish, ray, skate
Class Pisces	True or bony fish
Class Amphibia	Salamander, frog, toad
Class Reptilia	Turtle, snake, alligator, crocodile
Class Avis	Birds
Class Mamallia	Kangaroo, opossum, bat, sea lion, armadillo, whale, man

TABLE 5-3

PARTIAL LISTING OF COMMUNICABLE DISEASES THAT MAY BE ASSOCIATED WITH WATER AND WASTES

Name of Disease	Nature of Infection	Mode of Transmission
Actinomycosis	Fungus-like by Actinomyces hominis and bovis	Contact with contaminated material. Hogs and cows are passive carriers
Anthrax	Skin infection first, by B. anthracis. Spore former	Contact with infected animals, hides, or hairs
* Cholera	Enteric: by V. coma	Water
Diphtheria	Throat: by C. diphtheriae	Direct contact or soiled article, milk
* Amoebiasis (including dysentery)	Enteric, may be hepatic, by E. histolytica	Water, carriers among food handlers, flies

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TABLE 5-3 (Cont.)

Name of Disease	Nature of Infection	Mode of Transmission
* Dysentery, bacillary	Enteric, by Sh. dysenteriae, paradysenteriae, etc.	Water, food, milk, flies, carriers are common
Encephalitis infectious	Central nervous system, by several types of viruses	Some not clear, horses and birds, animal reservoirs, mosquitoes
* Paratyphoid fever	Enteric, by Sal. paratyphi, schottmulleri and hirschfeldii	Water, milk, food, etc. soiled by carriers of flies
Plague: Bubonic septic and pneumonic	Local or general, by Paseurella pestis	Rat-to-man by fleas, or direct man-to-man in pneumonic type
* Poliomyelitis, Echo and Coxsackie virus infectious	Central nervous system or general, by virus	Respiratory, direct contact, water, milk, flies
Scarlet Fever	General, by Strep. pyogenes, beta type	Respiratory, fomites, milk
Septic Sore Throat	Throat, by Strep. pyogenes, beta type also a bovine type that spreads in cattle	Respiratory, fomites, milk
Smallpox (Variola)	General, with skin manifestation by virus	Respiratory, aerial, fomites
Syphilis	Genital and general, by Treponema pallidum	Venereal, or contact with article freshly soiled with discharge or blood
Tetanus	Central nervous system	Wound soiled with dust, soil manure
Trichinosis	Muscle, by Trichinella spiralis	Eating inadequately cooked infected pork. (Raw garbage fed to hogs)
Tuberculosis pulmonary	Pulmonary, by Mycobacterium tuberculosis	Respiratory, fomites or article soiled with sputum
Tuberculosis other than pulmonary*	Local, bone, lymph-nodes, joint, by both human and bovine Tubercle bacilli	Sputum, milk or other food

TABLE 5-3 (Cont.)

Name of Disease	Nature of Infection	Mode of Transmission
Tularemia	General, by Pasteurella tularensis	Skin-infected rabbit or hare, bite of deerfly or tick, ingestion of infected food or water
* Typhoid Fever	Enteric, by Salmonella typhosa	Water, food, milk, flies, shellfish, about 4% become permanent carriers
Typhus Fever epidemic	General, by Rickettsia prowazekii	Body or head lice. Man serves as reservoir
Typhus Fever murine, endemic	General, by Rickettsia mooseri	Fleas in rat-to-rat, rat-to-man
Undulant Fever (Brucellosis)	General, by Brucella melitensis, abortus, suis (cows, pigs, goats)	Flesh, blood, or milk of infected animal
Haemorrhagic Jaundice (Weil's Disease) Leptospirosis	General, but chiefly in liver, by Leptospira icterohaemorrhagicae	Water, food or article contaminated by rat's urine
Ringworm	Skin, by Microsporum, trichophyton or epidermophyton (molds)	Direct contact, article worn by infected person, swimming pool
Schistosomiasis	Blood worm, Schistosoma (3 species)	Penetration of cercariae in water into skin of foot or leg upon drying
Vincents' Infection (trench mouth)	Mouth infection, by Fusospirochaetes	Oral contact with infected person or carrier. Common drinking cup
* Infectious Hepatitis	Enteric, by virus	Water, food, milk, and possibly flies contaminated with infective fecal material

* Major water-borne diseases

Pathogens
PRACTICE
SANITATION

Figure (5-2)

PRECAUTIONS AND PERSONAL HYGIENE

Because the possibility exists for every particle of sewage to contain disease bacteria, it is important that operators take every precaution to protect against diseases. Typhoid and tetanus are two of the common diseases that can be avoided by getting shots on a prescribed basis. All operators should obtain this protection and any other preventive protection prescribed by their physicians. It should be noted from Table 5–3 that many of the diseases can be transmitted from hand to mouth. The operator can prevent this type of transmission by good personal hygiene. Rubber gloves can be worn for direct handling of sewage or sludge. Hands must be washed after contact and should be rinsed in a bactericidal solution. Food or drink should be kept in office areas and care should be exercised to prevent contamination. Remember that sewage does carry disease organisms and that they can be transmitted to any person contacting the sewage. The importance of personal cleanliness and good working habits cannot be overemphasized.

DIFFERENCES BECAUSE OF SOURCES

Characteristics of wastes are dependent to a great extent on the source of the waste. For the purpose of this manual, these sources have been designated as agricultural drainage, storm drainage, solid wastes, urban runoff, sanitary sewage, industrial wastes and radioactive wastes.

1. **Agricultural Drainage.** Agricultural drainage can contain any of the other types of waste. People and animals and all of their associated activities contribute to the drainage. The trend toward confinement feeding of animals has caused a tremendous increase in the problems associated with disposal. Irrigation drainage picks up nutrients, pesticides, herbicides, and other organic matter before reaching water courses. As cities start reaching into farm territories, some of these wastes may reach the municipal system.

2. **Storm Drainage.** Storm drainage can affect all of the other sources. Storm flows do not usually contain high concentrations of chemicals because the flows are high. If the storm flows reach sewers, the hydraulic overload can dilute the sewage and make it difficult to treat even if the plant is large enough to receive it. In all cases, storm flows should be handled and controlled separately from other waste sources. For many years, storm drainage has been considered to be clean enough to go to receiving streams without treatment. MPNs have been high in many of the storm drains indicating contamination from warm-blooded animals. Even storm flows from mountain recreation areas are showing the effects of human use. It should be remembered that any use of water degrades it somewhat.

3. **Solid Wastes.** Drainage from landfills, open burning, incineration and plain dumping has become a problem in many areas. Solid wastes are organic materials and create an oxygen demand in drain waters. They also can contain disease organisms and can constitute a hazard. Flies, mosquitoes, and rodents inhabit these areas and can become vectors in the transmission of diseases. People dispose of anything they do not want and almost any kind of toxic chemical may appear in a solid waste disposal area. It is in the foreseeable future that all these drainages will be controlled or treated.

4. **Urban Runoff.** Urban runoff is normally controlled in storm sewers with sanitary sewage being exluded. Even with this exclusion, the urban drains contain undesirable material that should not be allowed to enter a water course untreated. Studies are underway to find and implement methods of controlling and treating this waste.

5. **Sanitary Sewage and Domestic Waste.** Sanitary sewage and domestic waste characteristics have been previously described. There are, however, hundreds of septic tanks still in use for domestic wastes. In many cases, the drainage from these tanks with their drain fields still reaches water courses. The drain water carries oxygen demanding matter, nutrients and other undesirable substances. Metropolitan planning agencies are promoting centralized treatment, and it is hoped that individual drainages will be eliminated or at least minimized.

Septic tank pumping is a common practice which delivers extra wastes to many of the centralized sewage treatment plants or to solid wastes disposal areas. Sometimes this poses problems to operators because of shock type loadings.

6. **Industrial Wastes.** Industrial wastes have been briefly described in the first part of this chapter. It should be repeated, however, that their main characteristic is their unpredictable behavior. These wastes are frequently strong, the flows are generally high, and they may be toxic. The wastes may be strong acidic or alkaline, high in color and possess high temperature. They may change the entire characteristics of an existing sewage treatment plant. It is vital to know the amount, strength, and treatability of these wastes before accepting them in a plant that is not designed to receive that specific waste.

7. **Radioactive Waste.** In addition to the many other pollutants entering a sewage treatment plant radioactive wastes have appeared in recent years. Radioactivity can enter a sewage treatment plant in a soluble form or be combined with other suspended or settleable sewage material. In a sewage collection system, radioactivity can result from the "down the sink" disposal of radionuclides after being used by hospitals and universities and other research organizations. Another source is the radioactivity originating from atmospheric fallout from nuclear weapons testing and entering the sewage system through the water supply. The isotopes generally used in research and as diagnostic and therapeutic tools in medicine usually have a relatively short half-life and therefore disappear rapidly. An exception is carbon-14 which is widely used by universities in tracer study. However, its energy is so weak it would only be considered a hazard if it were ingested in significant quantities.

Radioactivity cannot be visually observed or perceived by any of the senses or tested for by utilizing the chemical and physical tests available to a sewage treatment plant operator. The analysis of radioactivity requires a well equipped laboratory facility and very expensive and sensitive radiation counting equipment. The problem has not yet reached such proportions in the State of Washington so as to require routine monitoring at sewage treatment plants.

Radioactivity cannot be treated effectively by conventional treatment processes and when in a soluble form most of it will generally pass directly through a sewage treatment plant and be carried into the receiving stream. If the radioactivity is combined with suspended or settleable material it will tend to follow this material and become concentrated in the bottoms of settling tanks and grit channels; some will be absorbed in the biological growths on trickling filters and in the mixed liquor in activated sludge plants.

The disposal of radioactivity by dilution in sewage systems is specifically covered under the Department of Health Regulations on Radiation. The amount of radioactivity existing in sewage is not considered a hazard if the amount is below that specified in the regulations. According to existing regulations, the quantities of soluble radioactive material being disposed of by this method is dependent upon the chemical form of the material and the radiation hazard associated with it. This method of disposal also requires that the material be well diluted and well dispersed into the sewage system with large quantities of extra water to insure that acceptable levels are not exceeded. The disposal of high level liquid or solid radioactive wastes by dilution into a sewer is prohibited and the disposal of such materials requires the use of a licensed commercial disposal service.

There probably would be no direct health hazard to the sewage treatment plant operator even if the recommended levels of radioactivity in sewage are somewhat exceeded. However, since the use of radioactive materials is becoming more common, it is recommended that sewage treatment plant operators become familiar with all existing possibilities which could result in the discharge of radioactivity into the sewage system. The information which should be obtained is the type of radioactivity and the amount of the material being disposed of at any one time. If any problems arise or doubt exists concerning possible sources or the quantities of radioactive waste being disposed of in your sewage system, the Department of Health in Olympia, Washington should be consulted for assistance.

CHAPTER VI

BASIC CHARACTERISTICS OF SEWAGE TREATMENT AND DISPOSAL

INTRODUCTION

Treatment of sewage or industrial effluents may be defined as the use of any process or combination of processes whereby pollution is removed in order to render the effluents acceptable for discharge into receiving waterways or onto the surface of land areas. For the purposes of this basic operator's manual, the term pollution may be defined as the presence of any substance which, when placed on the surface of the land or diluted in a receiving waterway, would create a hazard to public health, create a nuisance condition, or render the receiving land area or waterway unfit for beneficial uses. It should be noted that almost all naturally occurring land areas and waterways contain varying amounts of impurities which might be called natural pollutants. It is really not possible to define the term pollution in a fashion which could be universally used because impurities, in varying amounts, are always present in our environment; as such, nearly everything with which human beings come into contact is actually polluted to a greater or lesser degree. It is precisely the degree to which something is polluted which becomes the important matter in considering the treatment of sewage and industrial effluents. For example, a naturally occurring lake may make an excellent environment in which to swim or bathe and for these purposes, such a lake could be considered to be nonpolluted. If, on the other hand, the same lake were to be used as a source of drinking water supply, the very same water which was termed nonpolluted for the purposes of swimming, might be considered to be polluted for the purposes of drinking water supply and thus require considerable treatment before its use would be considered safe.

Treatment of sewage or industrial effluents for the removal of pollutants does not in itself complete the necessary job of protecting our environment from these pollutants. Once removed from the effluent flow, the pollutants must be handled and disposed of in such a manner as to protect the environment from again being contaminated by the same pollutants. With this fact in mind, we may now define disposal of the pollutants removed by treatment processes as the application of any process which confines or changes the form of removed pollutants so as to render them inoffensive to our environment.

It may be seen that treatment without proper disposal is actually of no use as far as the ultimate aim of protecting our environment is concerned, and thus treatment and disposal must go hand-in-hand if the overall job of environmental protection is to be accomplished.

1. **Treatment Methods.** Sewage and industrial effluent treatment methods may be broadly classified as follows:

A. Primary Treatment. Primary treatment processes are those which act on the sewage or industrial effluents in a mechanical or physical way in order to remove floating or settleable solids and inorganic solids. Examples of such processes are: grit chambers, sedimentation basins, screens of various types and sewage grinders.

B. Secondary (biological) Treatment. Secondary sewage and industrial effluent treatment processes are those which utilize biological systems acting on dissolved or colloidal material contained in sewage or industrial effluents. Examples of secondary treatment processes are: activated sludge units, biological filters (trickling filters), waste stabilization ponds and digesters.

C. Tertiary Treatment processes. Tertiary treatment processes are those processes which act on both suspended and dissolved materials present within sewage and industrial effluents in such a manner as to remove pollutants not normally removed by secondary or biological treatment processes. Examples of tertiary treatment processes are: chemical coagulation and additional sedimentation; filtration through sand or other types of filters; contact with activated carbon and stripping or ion exchange processes for the removal of such items as ammonia nitrogen or hydrogen sulfide.

D. Natural (self-purification) Processes. Every waterway or land area has a certain ability to receive pollutants and to render these pollutants inoffensive or harmless to the environment. This naturally occurring process, whether it be on the surface of the land or within lakes or streams, is termed self-purification. The capacity of various land areas or waterways for self-purification varies widely, and the self-purification process can be easily overloaded with complete breakdown of the entire system. Natural self-purification processes would include sedimentation, biological treatment and chemical treatment such as ion exchange within soils. Also included would be assimilation of certain wastes into vegetable growth such as might occur when industrial effluents are spray-irrigated.

2. **Disposal Processes.** Just as an electric light bulb is of very little use when separated from a source of electricity, so is treatment of very little use if proper disposal methods are not followed.

Disposal methods may be broadly classified as follows:

A. Liquid Disposal. Liquid disposal may be further subdivided into three main categories as follows:

(1) dilution by discharge into streams or receiving waterways.
(2) evaporation into the atmosphere.
(3) percolation into groundwater supplies.
(4) transpiration into the atmosphere by the action of plants.
(5) incorporation into algal or bacterial cell materials.

B. Solids Disposal. Solids disposal may be further subdivided into three main categories as follows:

(1) land fill.
(2) incineration.
(3) dumping at sea.

3. **History.** Many modern sewage and industrial effluent plants are today performing a continuous service to Washington communities and industries. These plants are of many varied types and design; however, each individual installation has many things in common with all other installations. Each was designed and constructed to do a particular job of treatment in order to safeguard public health and to permit beneficial use of land areas, streams, lakes and rivers.

The profession of sanitary engineering which you as a treatment plant operator are so actively engaged in is a relatively modern endeaver. The beginning of sanitary engineering as far as a concerted effort to safeguard the environment is concerned occurred in the mid 1800's. In a little more than one hundred years, the field of sanitary engineering has progressed from a point where total public indifference was normal to the present day state of affairs where a concerned public is willing to spend millions of dollars each year in order to make an effort to reclaim our streams and rivers and make them once again a fit place for aquatic life to flourish and man to recreate.

4. **Necessity for Treatment and Disposal.** The need for proper sewage and industrial effluent treatment has its roots in antiquity. Man has always had a more or less gregarious nature and perhaps because of this has tended to congregate himself and his families into urban areas. This tendency for man to congregate into cities, of course, resulted in the concentration of wastes from man's activities within the cities. In addition to the domestic sewage thus produced, man's inventive nature has resulted in technological advances aimed at producing more and more goods for the use of man. The manufacture of such essential goods has not been without the production of industrial wastes which also demanded treatment. It is interesting to note the earliest large cities were provided with drainage systems for the conveyance of storm waters long before any thought was given to the treatment or disposal of sewage and industrial effluents. Evidently man thought it much more important to free his cellars and streets from the problems associated with storm water drainage than to protect himself from the ill effects of discharge of untreated domestic and industrial wastes to the land surface about him. The fact that man developed storm drainage systems long before he invented collection systems for domestic and industrial wastes has proposed a tremendous problem to today's treatment systems because man's next step in attempting to clean up his environment was to collect his domestic and industrial waste and simply discharge them into the storm drainage systems. Today, hundreds of years after the initial construction of such storm drainage systems, many of our large cities are still attempting to segregate storm drainage from sanitary sewage and industrial effluents.

As more and more untreated flows poured forth from the drainage systems of our large cities, the receiving waterways became less and less able to cope with the ever-increasing load thus placed on their natural purification capabilities. The situation became progressively worse with first the smaller bodies of water and then the large bodies of water becoming completely devoid of dissolved oxygen with resultant septic conditions and stench. The situation as it existed in the mid 1850's is well summed up by a quotation from a report prepared for the City of Boston in 1885 which read as follows: "As a result large territories were at once and frequently developed in an atmosphere of stench so strong as to arouse the sleeping, terrify the weak, and nauseate and exasperate everybody."

When man finally awakened to the fact that his untreated wastes were responsible for epidemics of waterborne diseases of all sorts and description, the complete loss of beneficial aquatic life in his streams, and the complete degradation of once sparkling streams into open sewers, he finally saw the necessity for ceasing his rape of the environment and began to expend at least a fraction of his energies towards the solution of the problems which he had created with his wastes.

Today the search for new and better treatment processes goes on at an ever-accelerating rate, and man has even begun to reclaim some of the streams which were, only a few years ago, grossly polluted.

As the volume of wastes increases with an increasing population, so must man's efforts at proper treatment and disposal increase if we are to avoid sliding back into the conditions that existed in the mid 1800's. In summary it may be said that treatment is simply necessary if man is to avoid fouling his own environment to a degree where it is no longer possible for man to exist. The problem is as simple as this.

5. **Classification of Treatment Types.** The present day technology of sewage and industrial effluent treatment may be divided into four main categories as follows:

A. Primary Treatment Devices. Primary treatment devices and processes include the following:

(1) coarse and fine screens.
(2) sewage grinders.
(3) sedimentation and flotation units.
(4) solids handling units including sludge dewatering and sludge incineration devices.

B. Secondary Treatment Units. Secondary treatment units are usually considered to be biological in nature and may be broadly classified into the following three types:

(1) biological filtration (trickling filters).
(2) activated sludge processes.
(3) aerated lagoons.
(4) sludge digesters.

C. Tertiary Treatment Units. Tertiary treatment units encompass a wide variation of equipment and processes. In general tertiary treatment units are designed to supplement primary and secondary treatment in order to perform the following functions:

(1) nutrient removal, that is, the removal of nitrogen and phosphorous in addition to that removed by primary and secondary processes.
(2) additional BOD and COD removals.
(3) removal of other difficult to treat organic or inorganic compounds.

Included among the many tertiary treatment processes are the following:

a. coagulation.
b. sedimentation.
c. filtration, either pressure or gravity types.
d. carbon adsorption.
e. polishing ponds.
f. stripping.

D. Miscellaneous Other Methods of Treatment. Many existing types of treatment incorporate one or more of the basic treatment classifications into a single unit operation which may actually perform several functions simultaneously. Among these types of treatment which are best described as miscellaneous are the following:

(1) oxidation ponds.
(2) Imhoff tanks and clarigesters.
(3) septic tanks.
(4) chemical treatment for enhanced sedimentation or pH adjustment.
(5) utilization of the self-purification capacity of streams or land areas.
(6) spray irrigation.

TREATMENT EFFICIENCIES

1. **Physical Removals from Primary Treatment.** As previously described, primary treatment devices act in a physical manner on suspended materials contained within waste flows. Efficiencies or percentages of removal of various components of waste to be expected with the use of well designed primary treatment units are generally considered to fall into the following ranges:

A. Suspended Solids. 40 to 70 percent removal.
B. Grease and Floating Material. 80 to 95 percent removal.
C. Settleable Solids. 80 to 95 percent removal.
D. Total Solids. 20 to 40 percent removal.
E. BOD. 20 to 40 percent removal.
F. Bacteria. 25 to 70 percent removal.

2. **Biological Removals from Secondary Treatment.** As previously discussed, secondary treatment processes generally involve the use of biological systems in order to achieve removal of nonsettleable solid materials or dissolved materials. Generally speaking, the efficiency or percentage removal achieved of various components of wastes which may be expected from well designed and operated secondary treatment units, are generally considered to fall into the following ranges:

A. Suspended Solids. 70 to 95 percent removal.
B. BOD. 80 to 95 percent removal.
C. Biodegradable Chemicals. 40 to 80 percent removal.
D. Bacteria. 90 to 98 percent removal.
E. Total Solids. 70 to 90 percent removal.

3. **Advanced Treatment Removals from Tertiary Treatment.** The application of additional treatment processes following secondary treatment varies widely in practice; however, the following removals have been achieved in tertiary treatment plants now in operation:

A. Suspended Solids. 100 percent removal.
B. Nitrogen. 75 to 90 percent removal.
C. BOD. 99+ percent removal.
D. COD. 95+ percent removal.
E. LAS (detergents). 99+ percent removal.
F. Phosphates. 97+ percent removal.
G. Bacteria. 100 percent removal.

COMPONENTS OF TREATMENT AND DISPOSAL

1. **Mechanical or Physical.**

A. Screening. The purpose of screening is to remove from the sewage or industrial effluent flow, some of the constituents which could clog or cause damage to pumps or interfere with subsequent treatment processes. Screening devices are, therefore, designed to remove the large suspended or floating organic solids which consist of bits of wood, cloth, paper, garbage; heavy inorganic solids such as sand and gravel, and metallic objects.

Screening devices may be of several types including bar racks, both hand or mechanically cleaned, wire mesh types usually mechanically cleaned, and perforated metal plate types also usually mechanically cleaned.

(1) bar racks. These consist of bars usually spaced 3/4 inch to 6 inches on centers. Those most commonly used provide clear openings of from one to 2 inches although wider openings are sometimes used. The majority of bar racks are set at an angle of from 45 to 60 degrees with the vertical although very large units are sometimes set vertically. Bar screens may be cleaned either manually or by means of automatically operated rakes. Bar racks which are intended to be cleaned manually should preferably be set at a slope of from 30 to 45 degrees with the vertical. Material strained from the waste flow by means of bar racks, requires further treatment before final discharge.

(2) screens. Screens with openings of 1/8 inch or less have been used in sewage treatment. They can be classified as band screens, disc screens, and drum screens. This type of screening device has not found widespread use at domestic sewage treatment plants in the past; however, new types of vibratory fine screening devices may be expected to play an increasing role in the future. Fine screen devices such as the drum screen are used in a few sewage treatment plants in the State of Washington, a notable example being the use of a rotary drum screen on the industrial waste sewer at the City of Yakima. There are widespread industrial applications for all manner of screening devices, and their use in industrial effluent treatment is quite common particularly in the food processing industry. Materials removed from sewage or industrial effluents by screens require further treatment before final disposition.

B. Solids Grinding and Shredding. The purpose of solids grinding or shredding is to reduce in size, large suspended or floating organic solids in order to prevent subsequent interference with other treatment devices. Grinders and shredders were developed for the primary purpose of making possible the return of the ground solids to the waste flow so that they might be more easily treated with other removed solids rather than attempting the separate disposal of such solids. Solids grinders and shredders are normally of two types as follows:

(1) separate screening grinders. These are devices of the hammermill or internal tooth type which shred solids by subjecting them to the internal action of knives or cutters rotated at relatively high speed. Separate screening grinders or shredders are commonly used in large treatment plants where mechanically cleaned bar racks are provided. They are normally so arranged that the materials mechanically raked from the bar racks are discharged into a hopper which in turn discharges the solids into the grinding device. After grinding, the solids are normally discharged back into the waste flow.

(2) comminution in sewage flow. Most small or medium-sized treatment plants as well as an increasing number of the larger treatment plants in use today, utilize types of sewage grinders commonly referred to as comminutors. These are machines which actually shred solids without removing them from the sewage or industrial effluent flow. These machines consist of a slotted cylindrical drum screen which is partially submerged in the waste flow. The screen slots are generally on the order of 1/4 inch. Material caught on the screen is cut by revolving cutters driven by a hydraulic or electric motor into pieces small enough to pass through the screen openings.

Another type of in-flow sewage grinding machine is the barminutor. This machine consists of a vertical rack of bars set partially submerged in the sewage flow and a travelling revolving set of cutter teeth mounted on a drum which moves up and down the face of the vertical bars and shreds material in the flow by the revolving action of the cutter teeth. Early models of barminutors were designed to run continuously and thus were subject to considerable wear. Later modifications have resulted in the use of a stop-and-go cycle controlled by water depth upstream of the vertical bars. It is possible to modify even the earliest types of barminutor machines so as to incorporate the stop-and-go principle by the simple addition of float switches upstream and downstream of the vertical bars.

The advantage of the in-flow sewage shredding devices is, of course, that the material to be shredded does not need to be handled by plant operators since it is caught and then shredded and returned to the sewage flow by the machines. Very large machines are currently available, ranging in size up to a 36-inch diameter comminutor or a 36-inch width barminutor machine. Even larger sizes are available on special order.

After varying periods of operational time cutter teeth and shear bars on these machines become dull and inefficient in their action. When this occurs new cutter teeth may be purchased from the manufacturer or the cutting members may be resharpened by the operator at the plant. Figures 6-1 and 6-2 illustrate typical comminutor and barminutor equipment.

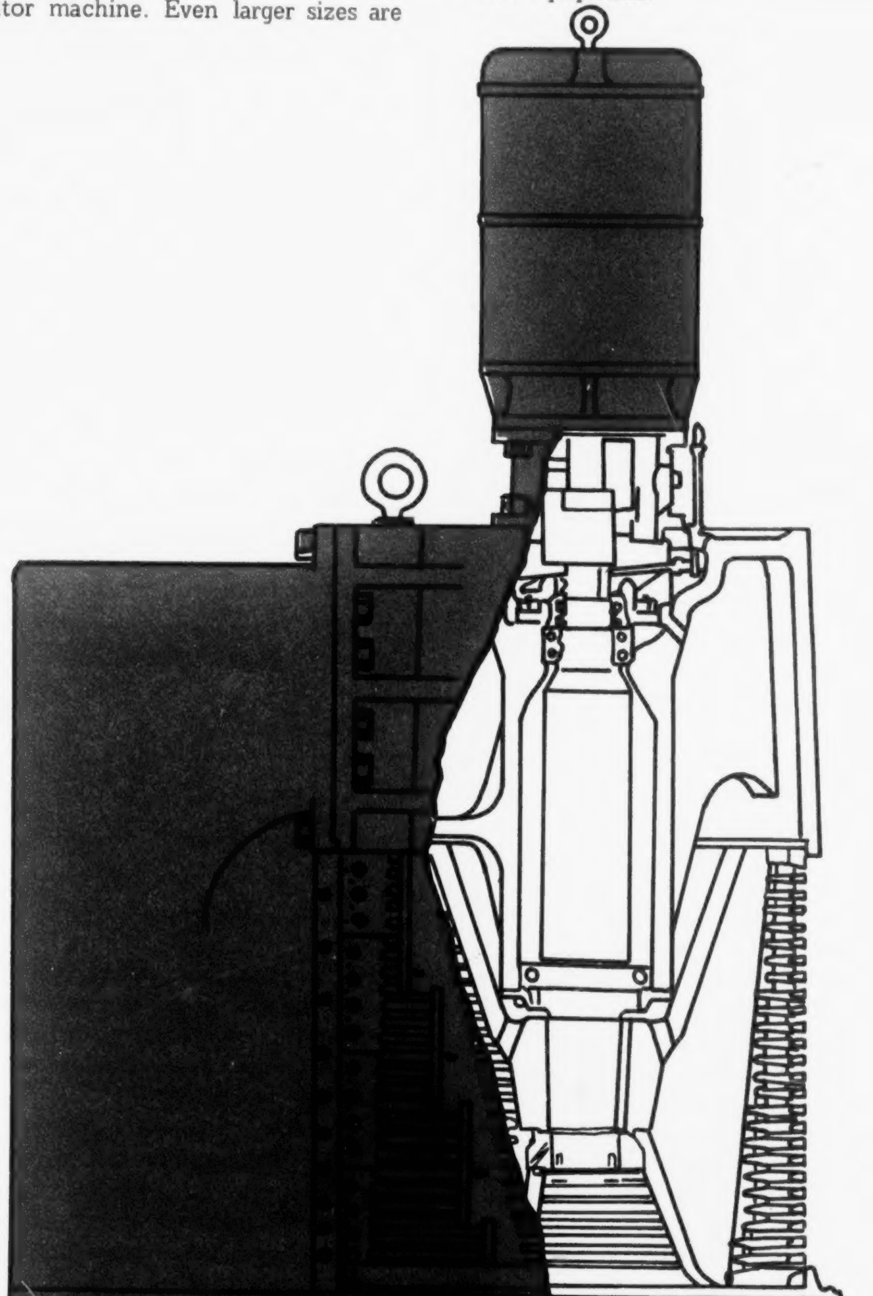


Figure (6-1)
TYPICAL COMMINUTOR EQUIPMENT

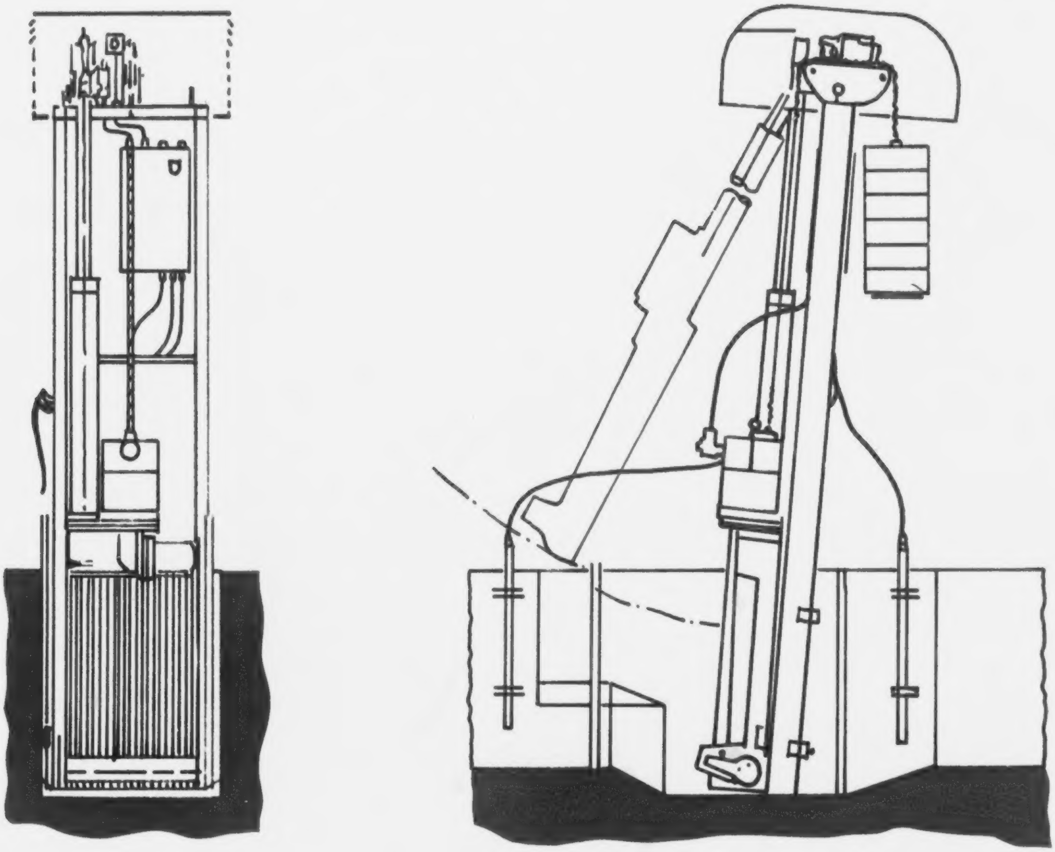


Figure (6-2)
TYPICAL BARMINUTOR EQUIPMENT

C. Grit Removal. Grit not removed from sewage prior to sedimentation can cause serious problems in pumping sludge or in circulation of sludge within a digester. Grit chambers are, therefore, often installed at treatment plants to remove dense mineral matter such as sand, gravel, and cinders. Grit chambers generally fall into one of three types. The simplest types of grit chambers are those in which the velocity of waste flow is maintained at or about one foot per second, either by use of proportional weirs on other types of depth control devices, or by the injection of diffused air.

Another method of grit removal utilizes clarifier-like mechanisms which are sized so as to cause not only grit but a certain amount of fine organic material as well to settle. The settled grit and organic material from this type of device is then classified by means of grit washing devices which remove the organics from the grit, returning them to the sewage flow, and rake the grit from the classifier for final disposal.

The third method for grit removal utilizes a hydraulic cyclone to remove grit from organic material. This type of device may be utilized either to remove grit from raw sludge collected in sedimentation basins or to remove grit from a mixture of settled grit and some organics which might be collected from a small sump preceding sedimentation tanks. In both cases pumps are used to feed the organics-grit mixture to the hydraulic cyclone. The pumps discharge tangentially into the hydraulic cyclone thus causing the mixture of grit and organics to revolve at a high rate of speed. The centrifugal force thus generated tends to force the heavier grit particles to the outside of the rotating flow stream. The grit particles are then scalped from the outside portion of the rotating flow stream and the inside portion of the flow stream which contains the lighter organic materials is returned to the sedimentation basin or to the flow process.

Each of the many types of grit removal methods is discussed in more detail as follows:

(1) velocity control by head control devices. The simplest type of grit removal devices normally take the shape of long, narrow channels provided with some sort of head control device at the downstream end of the channel. Head control devices in common usage include Parshall flumes and proportional weirs. The cross-sectional shape of the long, narrow channel is designed so as to maintain, as nearly as possible, a constant velocity no matter what the depth of flow in the channel. Flows in this type of grit removal equipment normally are controlled so as to have a velocity of from 0.75 to 1.0 feet per second. At this velocity heavy grit particles will settle to the bottom of the channel while lighter organic materials, for the most part, will pass through. This type of grit removal equipment can be either manually cleaned or equipped with mechanical scrappers for automatic cleaning. In most cases if the grit channels are designed to be manually cleaned at least two identical channels are provided so that while one channel is being cleaned, the other channel may be used.

Since it is very difficult to design a grit channel having a cross-sectional area which exactly matches the characteristics of the head control device, it follows that with widely varying waste flows, a variance in velocity through the grit channel may be expected. If velocities are allowed to exceed about one foot per second, then much fine grit will escape to be eventually troublesome in later stages of treatment; conversely, if velocity falls below 0.75 feet per second, organic material begins to settle thus producing a very dirty grit which rapidly becomes septic and odorous unless the grit is immediately buried. For these reasons the use of grit removal by head control devices is not as widely used in new treatment plant construction as it used to be. It should be noted, however, that there are many treatment plants utilizing this type of grit removal equipment which do an adequate job of grit removal. Figure 6-3 illustrates this type of grit channel.

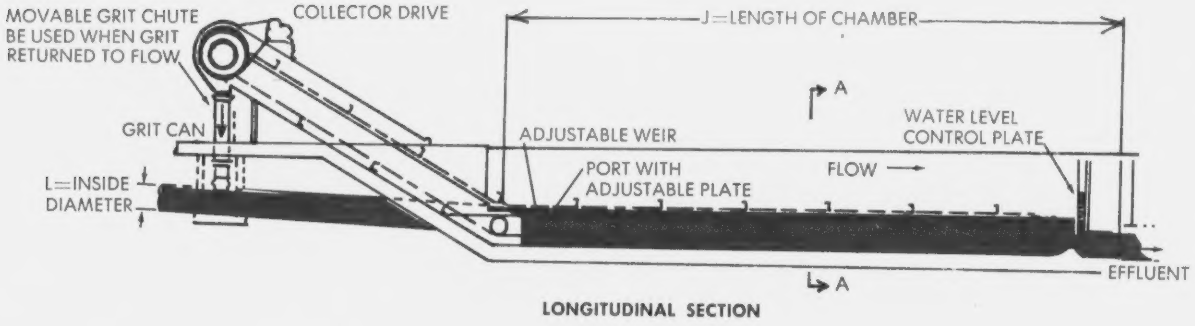


Figure (6-3)
TYPICAL VELOCITY CONTROL
GRIT CHAMBER

(2) velocity control by aeration. During recent years, removal of grit by the use of compressed air with controlled upward velocity has gained popularity among sewage plant design engineers. This system consists basically of a rectangular basin having filleted side walls and having a diffused air discharge system located at one side. The discharge of compressed air through the air diffusion device produces a rolling action within the aerated grit chamber thus causing settled materials to be swept across the bottom into a sump usually located under the air diffusers. The theory behind this type of grit removal is that velocities within the aerated grit chamber may be

controlled at will by varying the amount of compressed air blown into the system. In theory, lighter particles which tend to settle at the far end of aerated grit chambers are swept back across the bottom by the rolling action and are resuspended into the waste flow by the upward velocity produced by the diffused air. One disadvantage of this type of system is that there is no easy means of inspecting to tell if adequate grit removal is being obtained. Another disadvantage is that air supply and resulting velocities are dependent upon the condition of the air diffuser system. The major advantage of the system is that for all practical purposes, operation is independent of the sewage flow, once the proper rolling velocity for grit removal has been established by trial and error. Figure 6-4 illustrates this type of equipment.

(3) detritus machines. Detritus machines for grit removal generally consist of a concrete or steel chamber large enough to produce settling velocities for grit under all conditions of sewage flow. The chamber is usually equipped with a rake mechanism or conveyor system which conveys grit or settled organic materials to a grit washing device which is incorporated into the design of the machine. The function of detritus machines is to scrub or wash the grit and organics mixture which accumulates in the grit chamber and at the same time remove it from the channel or chamber to a point where it can be transported away for disposal. Agitation of the grit in the sewage separates organic matter from the grit and the organic matter is held in suspension while the grit is being moved by a conveyor.

Several well known manufacturing companies specializing in sewage disposal equipment have been successful in perfecting this type of equipment. A description of such equipment might be helpful to operators of sewage plants if consideration is being given to possible installation for the purpose of obtaining better results and the lessening of manpower requirements. The Dorr Company has developed equipment consisting of a revolving mechanism in the bottom of a square grit chamber which pushes grit into a channel. The channel slopes upward to a drainage deck. Grit is drawn up this inclined channel by means of a reciprocating rake mechanism which cleans and drains grit at the same time. An organics return pump is often utilized with this type of equipment in order to recirculate the organics separated from the grit back into the grit chamber. This type of equipment may be either operated continuously or operated on a time clock control basis according to the needs of individual plants. The Eimco Company also makes

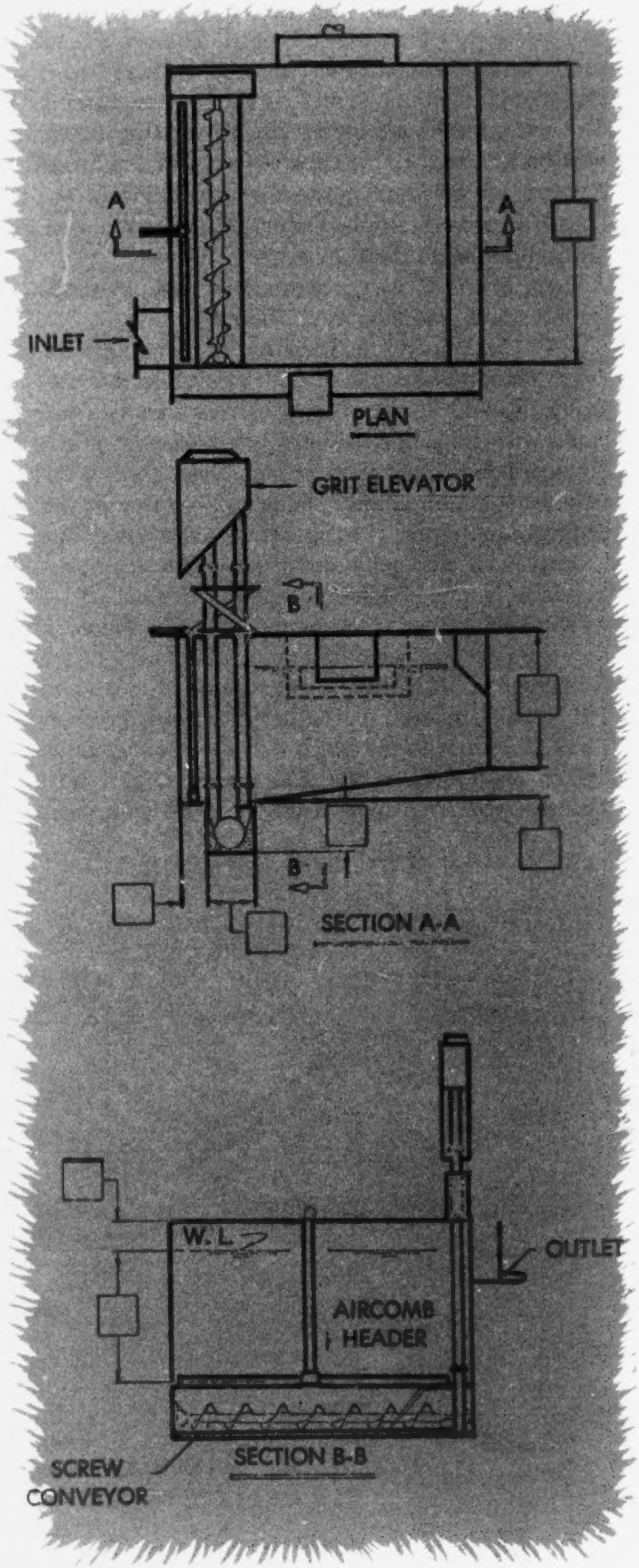


Figure (6-4)
TYPICAL AERATED GRIT CHAMBER

a machine which is essentially the same as that previously described except that a screw-type conveyor is used for washing and transporting grit rather than a reciprocating rake mechanism.

The Link Belt Company makes a machine for narrow rectangular tanks. This machine consists of a collector scraping settled grit to a screw conveyor and a washer located at one side of the center of the chamber. The screw operates in a steel trough at an angle of about 30 degrees with the horizontal and moves grit slowly up and above the water level. Collector flights are set on an angle to the direction of travel and turn grit over and over which frees the grit from lighter organic material which has settled with the grit. Heavy organic matter is separated from grit by the screw and is floated by the current of water created and directed by baffles in the influent channel and a corresponding baffle and cover plate over the screw.

An apparatus made by the Chain Belt Company employs the recirculation principle. If grit containing a high percentage of organic matter is being removed by the mechanism, it can be returned directly to the sewage stream and when it again reaches the grit chamber and rapidly flowing sewage, organic matter is well mixed with the flowing sewage and will be carried out of the channel. Velocity is controlled by using a proportional weir.

The Jeffrey Manufacturing Company makes a type of apparatus which uses a scraper conveyor. The collector itself continues up the incline which is a continuation of the bottom of the tank. Plow flights spaced between conveying flights separate out organic matter. Figure 6-5 illustrates some typical examples of detritus machines.

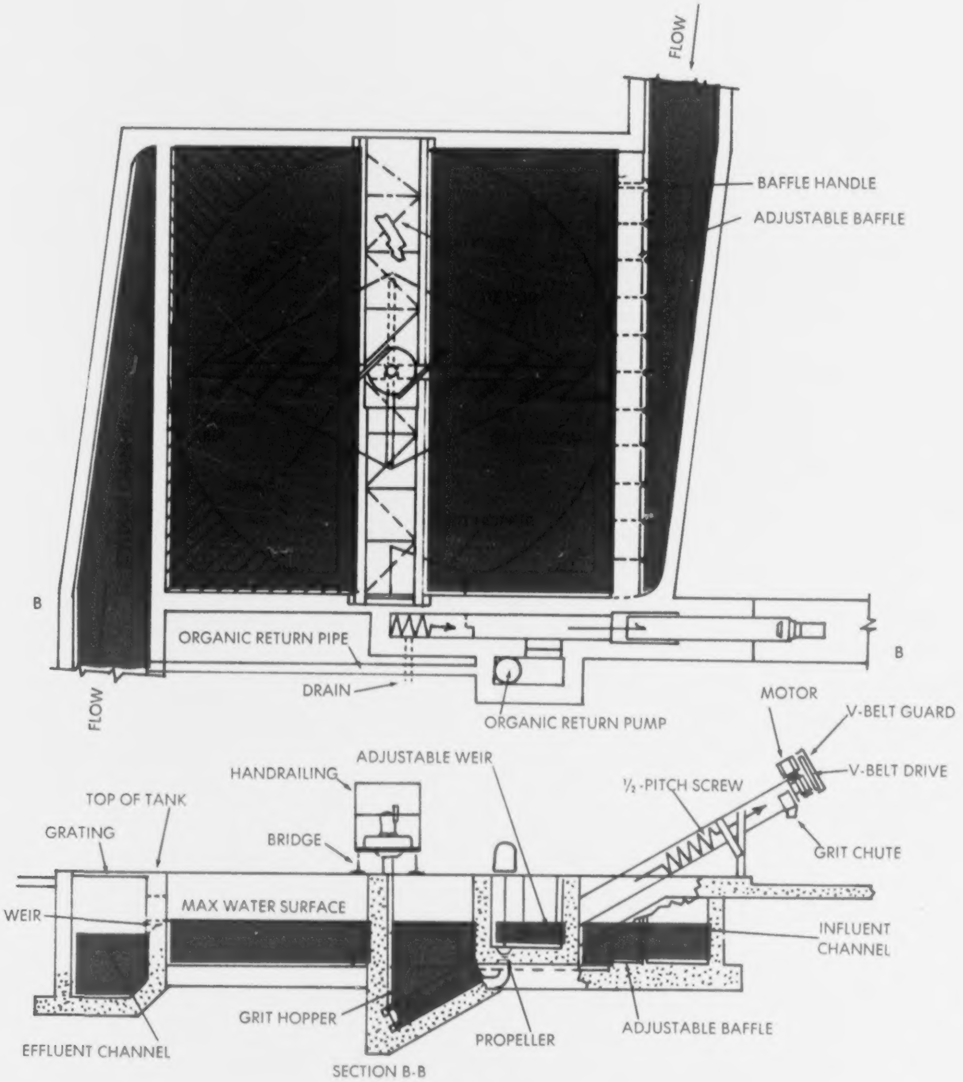

FLOW
BAFFLE HANDLE
ADJUSTABLE BAFFLE
B
ORGANIC RETURN PIPE
DRAIN
FLOW
ORGANIC RETURN PUMP
B
MOTOR
V-BELT GUARD
HANDRAILING
ADJUSTABLE WEIR
V-BELT DRIVE
TOP OF TANK
½-PITCH SCREW
GRATING
BRIDGE
GRIT CHUTE
MAX WATER SURFACE
WEIR
INFLUENT CHANNEL
GRIT HOPPER
EFFLUENT CHANNEL
PROPELLER
ADJUSTABLE BAFFLE
SECTION B-B

Figure (6-5)
TYPICAL DETRITUS MACHINE

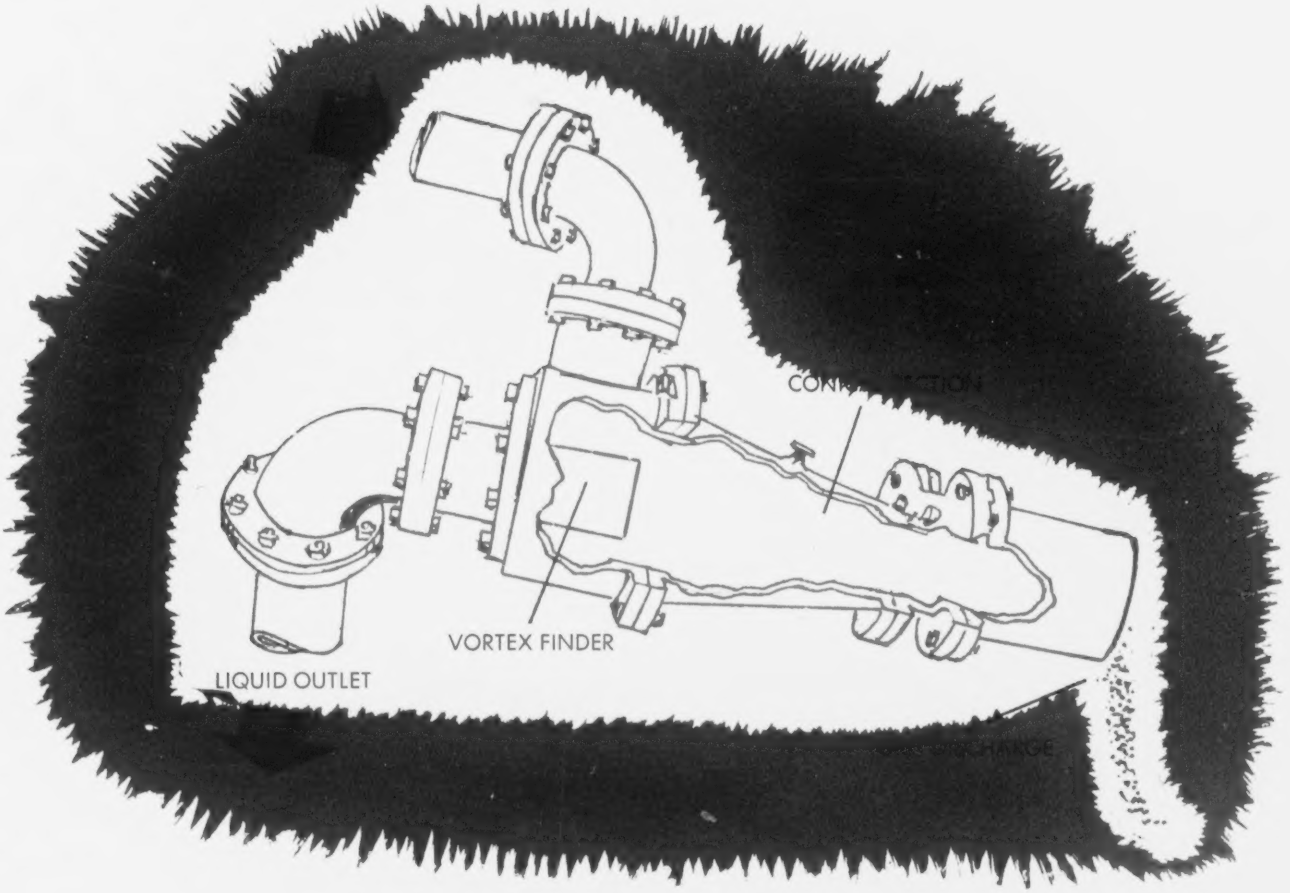


Figure 6-6 Typical Hydraulic Cyclone

(4) cyclonic separation. Hydraulic cyclones for the separation of grit from organic matter are finding an increasing use in waste treatment plants currently being designed. The hydraulic cyclone basically consists of a cone-shaped metal casting having a tangential inlet located at the large end of the cone and an adjustable drawoff point located at the apex or small end of the cone. In operation, grit-containing materials which have been collected by allowing to settle in separate grit chambers, are pumped through the tangential inlet at a high rate of speed. The tangential inlet causes a very rapid rotation of the grit-laden flow and the rapid rotation results in the heavier specific gravity materials being thrown to the outside of the spiral by centrifugal force. These heavier specific gravity materials are withdrawn by the adjustable outlet located at the orifice along with a small amount of water from the flow pumped to the cyclone. The major portion of the flow pumped to the cyclone along with the lighter materials is withdrawn from a central withdrawal point located at the large end of the cyclone and returned to the sedimentation process. Figure 6-6 illustrates this equipment.

D. Disposal of Grit Screenings and Ground Solids. The disposal of materials such as grit and screening removed from waste flow is usually accomplished in one of three ways. Probably the most widespread disposition of grit and unground screenings is by means of burial. Another method of disposal of screenings, and in some cases grease skimmed from other treatment processes, is by incineration. The incineration of these materials is not widespread in use in smaller plants, however, because of the large investment required for construction of proper incinerators. The most popular method for the disposition of ground screenings is, of course, to return them into the waste flow from which they are again removed by primary sedimentation and handled along with the raw sludge thus produced.

Since burial of grit and screenings is probably the most widespread single method of disposition presently being used, some discussion of proper methods of handling and burial is in order. As has been previously discussed it is quite often difficult to remove grit from waste flows without removing at least a small fraction of putrescible organic materials. Screenings, of course, always contain a very large amount of putrescible material. Such grit and screenings cannot be allowed to accumulate in piles or open areas around treatment plants because they will very rapidly decompose causing odor problems and will attract flies and rodents. Grit and screenings should be placed into covered drums immediately upon their removal from the sewage flow and the contents of the collected drums should be buried at least daily. The practice of dumping these collected solids in open trenches for later earth cover is not particularly desirable. If these materials are to be buried, they should be covered at the end of each day in order to minimize odor, insect and rodent infestations.

E. Preaeration Processes. In many instances sewage or industrial effluent flows reaching a treatment plant have traveled for a considerable length of time in the sewer network before reaching the plant. Depending upon the length of time in transit, the flows reaching the plant may be without dissolved oxygen. Flows reaching the plant in this condition are termed septic and it may be necessary to aerate the flows prior to primary sedimentation. Such aeration is termed preaeration and is done in order to introduce at least a small portion of dissolved oxygen into the flow. If flows are introduced into primary sedimentation tanks when they are in a septic condition, the efficiency of the primary sedimentation basins is adversely affected and the basins themselves may give rise to obnoxious odors. The decomposition of settled sludge under zero oxygen conditions at the bottom of the tank may cause the production of various gases, most of which are odorous. These gases are released in the form of very small gas bubbles which tend to cling to solids and float the solids to the surface of the sedimentation basin. To eliminate these conditions, it is possible to provide dissolved oxygen in the flow before the flow reaches the sedimentation basins. Preaeration chambers accomplish this by aerating the sewage usually for a period of approximately 30 minutes detention time before the flows are allowed to pass into the sedimentation basin. Depending upon the amount of oxygen required, it may be possible to provide sufficient oxygen into the flow by use of aerated grit chambers which would then serve the dual function of grit removal as well as providing some oxygen in the waste flow.

Rather than provide a separate chamber in which to aerate the sewage, a few older treatment plants were equipped with a combination type of primary sedimentation basin which was divided into both an aeration and a settling section. This type of equipment was usually of the circular clarifier type and a steel baffle was installed thus dividing the clarifier into two sections. The section into which the flow first was introduced was equipped with air diffusion devices and the waste flow was thus aerated before passing on into the outer chamber in which sedimentation took place. The use of this type of equipment does not appear to be in widespread favor with present design engineers.

F. Sedimentation. The purpose of sedimentation in sewage and industrial waste effluent treatment plants is to remove as many as is possible of settleable or floatable solids contained in the waste flow. Primary settling tanks remove materials which are settleable or which will float to the surface from waste flows prior to discharge to a receiving waterway, in the case of primary treatment plants, or to secondary treatment units in the case of secondary or tertiary treatment plants. Sewage and industrial waste flows carry suspended particles because of the velocity and mixing action common to collection systems. If the velocity of flow and mixing action are greatly reduced as in the case of sedimentation basins, most of the solid material contained in the waste flow will settle to the bottom or float to the top as a scum. These solid materials, of course, are removed by the action of primary settling basins. Primary settling basins are simply large tanks designed so as to provide, as nearly as possible, a uniform dispersion of the waste flow throughout a large basin so that velocity and mixing currents are greatly reduced. Under these circumstances, solid materials which were carried in suspension by the waste flow are allowed to settle to the bottom or to float to the surface for collection. Sewage and industrial waste flows also contain considerable dissolved material which cannot be removed by primary sedimentation. This dissolved material is passed on to the receiving waterway, in the case of primary treatment plants, or passed on to secondary units in the case of secondary or tertiary treatment plants. After undergoing either chemical or biological treatment in secondary and tertiary units, a large percentage of the dissolved material once contained in the sewage flow is converted into solid particles (bacteria) which can then be removed by secondary sedimentation basins. The action of both primary and secondary sedimentation basins is the same; however, more care must be used in the design of secondary sedimentation basins than for primary types since the solids created by the action of biological or chemical treatment often contain a great percentage of water and thus are more difficult to settle than are primary waste solids.

Both primary and secondary sedimentation tanks can be divided into two broad categories as follows:

(1) mechanically equipped basins. Various types of mechanically equipped primary or secondary sedimentation basins are in current usage today. Broadly speaking, all sedimentation basins either take the form of circular tanks or rectangular tanks. In the rectangular type, sewage flows from one end of the tank to the other and the sludge which settles to the bottom is moved by scrapers to a hopper located either at the inlet or outlet end of the tank. Rectangular tanks may be in single units or in a series of units. The length of the tank is usually several times the width. Deposited sludge is moved to a hopper at one end, either by wood flights mounted on parallel strands of conveyor chain or by a single bottom scraper mounted on a carriage which moves on rails fastened to the tank walls. Chains and scraper flights are carried on submerged sprockets, shafts, and bearings and are driven by a motor. The scraper flights may be arranged to remove floating material from the tank on their return path. The single bottom scraper type of mechanism may be either towed by cables connected to winches or may be powered by traction drive which pushes the scraper back and forth across the length of the tank by the action of a traction drive running on the wall.

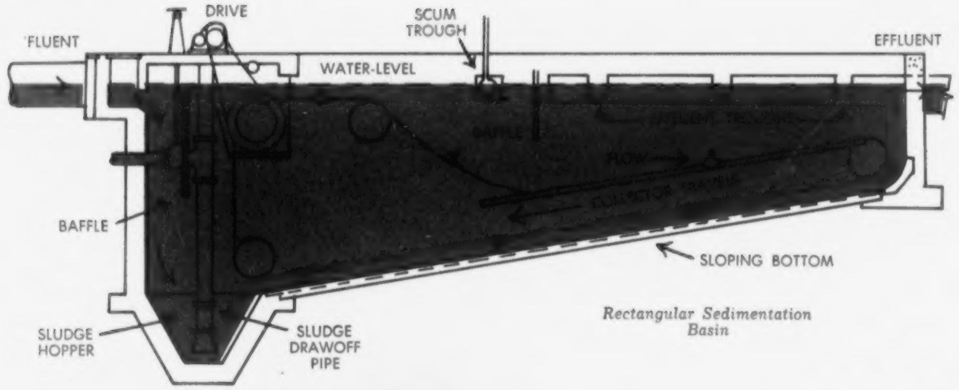
Circular sedimentation tanks are probably the most common type of sedimentation basin now in use and most often consist of a circular tank in which the waste flow is introduced into the center into a feed well which dissipates inlet velocities. The waste moves radially from the feed well to a weir and overflow trough at the outside edge of the tank. Settled solids are raked to a hopper near the tank center by arms attached either to a drive unit at the center of the tank or a traction unit operating on the tank wall. In primary tanks, floating material usually is moved to a collection point by a skimmer attached to the sludge collecter. Settled solids are usually scraped to a central sludge collection hopper by the action of the plows attached to the bottom of the sludge collector rake arm. Figure 6-7 illustrates typical rectangular and circular sedimentation basins.

Circular sludge collection mechanisms may also be adapted for installation into square sedimentation basins. In this case, the mechanism is essentially the same as previously described with the exception that a hinged arm is provided at the outer end of the rake arm. If this hinged arm is equipped with a counterweight and is so constructed that as the main rake arm approaches the corners of the square tank, the hinged arm swings out in order to clean the corners of the tank.

Another type of circular mechanism is often employed when difficult to remove sludges or sludges which decompose rapidly are present. This type of circular mechanism acts like a giant vacuum sweeper and is generally composed of a set of rotating pipes or orifices through which large volumes of liquid from the lower portion of the sedimentation tank are pumped. This type of mechanism removes sludge very rapidly from a sedimentation tank; however, the removed sludge is very dilute with respect to solids concentration. The sludge suction type of mechanism is almost always used today as a secondary type of clarifier and then generally only in conjunction with the activated sludge type of secondary treatment. Figure 6-8 illustrates a typical sludge suction type sedimentation basin.

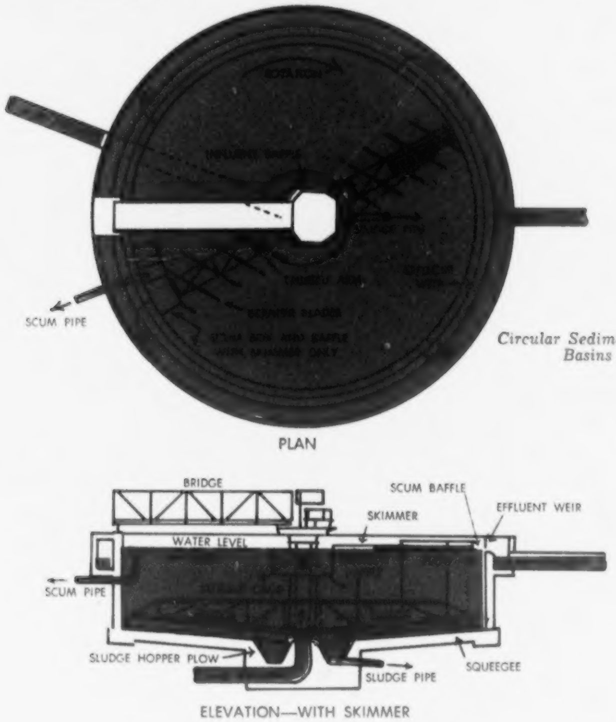
(2) nonmechanically equipped basins. Small rectangular or circular sedimentation basins may have a sludge collection hopper covering the entire bottom of a tank in lieu of sludge collection mechanism. Since hopper slopes must be relatively steep, the use of this type of sedimentation tank is confined to rather small sizes in order to avoid excessive tank depth. Older sewage treatment plants sometimes were constructed with nonmechanically cleaned sedimentation basins which had a series of multiple hoppers across the entire bottom of the tank. The use of these multiple hoppers requires that each hopper be equipped with a separate sludge withdrawal pipe and that each sludge withdrawal pipe be either manually or automatically valved so that sludge can be withdrawn from each hopper on a regular basis. The use of nonmechanically cleaned sedimentation basins has become less and less popular as better and less expensive mechanical collection equipment has become available.

(3) factors influencing sedimentation. Sedimentation is affected by the strength and freshness of sewage or industrial waste and the density, shape and size of the particles. Strong wastes usually settle more readily than do weak wastes. On the other hand septic wastes settle less readily than do fresh wastes because the particle sizes are



FLUENT
DRIVE
SCUM TROUGH
WATER-LEVEL
EFFLUENT
BAFFLE
FLOW
BAFFLE
SLOPING BOTTOM
SLUDGE HOPPER
SLUDGE DRAWOFF PIPE

Rectangular Sedimentation Basin



ROTATION
SCUM PIPE
PLAN
BRIDGE
SCUM BAFFLE
SKIMMER
EFFLUENT WEIR
WATER LEVEL
SCUM PIPE
SLUDGE HOPPER PLOW
SLUDGE PIPE
SQUEEGEE
ELEVATION—WITH SKIMMER

Circular Sedimentation Basins

Figure (6-7)
TYPICAL SEDIMENTATION BASINS

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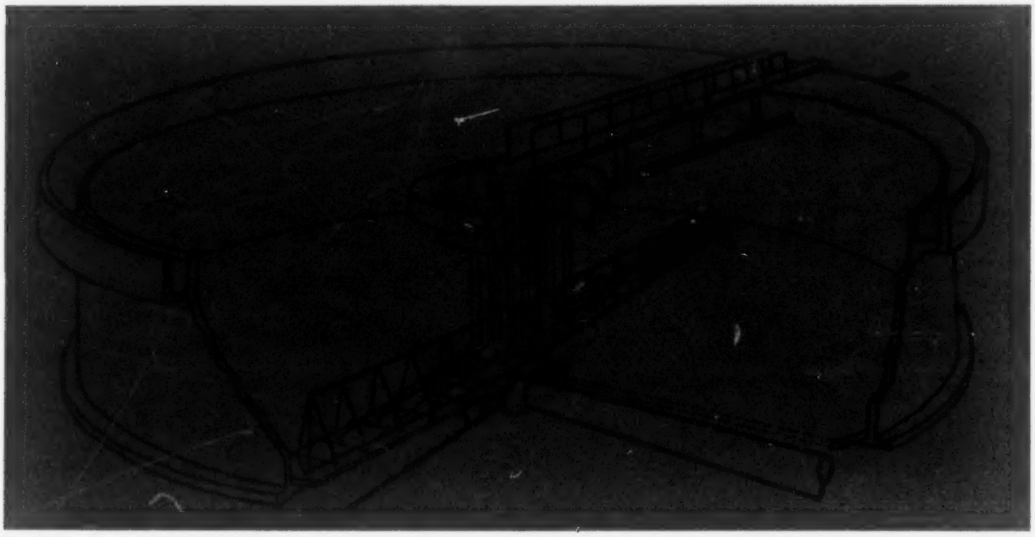


Figure (6-8)
TYPICAL SLUDGE SUCTION TYPE
SEDIMENTATION BASIN

reduced by the action of biological organisms and also the particles tend to be lifted by gas released by the action of biological organisms. Dense particles settle more rapidly than do lighter ones. A particle with a large surface area in relation to its weight settles slowly. One with an irregular shape has greater frictional drag and settles more slowly than a particle with a spherical shape.

There are quite a number of terms which have come into general usage among treatment plant operators and design engineers in order to describe the various factors which affect sedimentation.

One of these terms is detention. Detention period may be defined as the theoretical time required for the waste to flow through a sedimentation tank at a given rate of flow. Many regulatory agencies have requirements as to a minimum allowable detention time for sedimentation basins. Usually these minimum allowable times are on the order of from one to two hours.

Another term often used is overflow rate. Overflow rate may be defined as the effluent flow rate from a sedimentation tank in gallons per square foot of surface area per day. Again, many regulatory agencies have placed certain upper limits on allowable overflow rates. These upper limits usually range from 900 to 1,200 gallons per day per square foot, in the case of primary sedimentation basins and from 600 to 900 gallons per day per square foot in the case of secondary sedimentation basins. If one actually stops to consider the overflow rate, it can be noted that overflow rates are actually expressed as a volume of water divided by an area. As such, overflow rates actually express the average upward velocity in feet per day that the waste contained in the sedimentation basin would have if overflow was entirely uniform over the entire surface area of the basin. When considered from this viewpoint, it can be seen that overflow rates are actually quite important, since, the upward velocity of the waste in a sedimentation tank must be very small if the lighter weight particles are to settle to the bottom and not be buoyed upward by the upward velocity.

Another term commonly used when discussing sedimentation tanks is weir rate. The weir rate may be defined as the rate at which water flows over a unit length of weir. In the case of sedimentation tanks, weir rates are most often expressed in terms of gallons per foot of weir per day. Most regulatory agencies have maximum upper limits allowable for weir rates and these upper limits are generally on the order of 15,000 gallons per foot of weir per day. Weir rates are significant because if a very large volume of water is passed over each foot of weir, high velocities will be created in the area of the sedimentation tank immediately adjacent to the weir. These high velocities can tend to pull solids, which may have been settled to the bottom, back out of the tank, thus reducing the efficiency of the sedimentation basin.

(4) sludge collection and removal. As previously described, sludge which settles to the bottom of sedimentation basins must be collected and removed from the basin. In the case of mechanically equipped basins, the collection is provided by mechanical devices which scrape or push the sludge to a hopper located in the bottom of the sedimentation tank. In the case of nonmechanically equipped basins, the entire bottom of the basin is either a single large hopper or a number of smaller multiple hoppers, and the sludge is allowed to settle directly into these hoppers. Once collected into the hoppers, it is necessary that the sludge be removed from the basin. The most common method of sludge removal from the basins is by means of pumping from sludge withdrawal pipes located in the bottoms of the hopper or hoppers. Other withdrawal methods sometimes employed, use airlift pumps for removal of sludge or remove the sludge by gravity utilizing the depth of waste liquid above the sludge hopper to force the sludge through a collection pipe. In any case, best practice indicates that sludge should be removed on a periodic basis in the case of primary sedimentation basins and almost continually in the case of secondary sedimentation basins. Usually the periodic sludge removal can be controlled by means of a time clock which in turn controls sludge or airlift pumps or in the case of gravity flow, controls a system of valves which are opened and closed depending on which sludge hopper is to be drained.

(5) scum collection and removal. Scum collection is normally practiced only on primary sedimentation basins. In circular or square basins, scum is usually collected by means of a skimmer arm which rotates with the sludge collection rake mechanism. This skimmer arm tends to force floating scum to the outer edge of the tank where it is finally pushed up an inclined ramp and discharged into a scum pit. Scum thus collected can then be pumped on an intermittent basis from the scum pit as required. In the case of rectangular sedimentation basins, scum may be swept to the outlet end of the tank by the action of the wooden scraper flights or may be sprayed to the outlet end of the tank by means of water jets directed to move the scum along the surface of the water. In either case, the scum can then be collected by means of several types of scum collection mechanisms. Probably the most common type is a slotted pipe section which is set across the water surface and equipped with wall-mounted bearings in such a manner that the trough may be rotated and dipped under the surface of the water. Rotating the trough downward, causes the scum to flow into the slotted pipe and the scum thus collected, flows through the slotted pipe into a scum pit. Another type of mechanism utilizes a revolving blade mechanism which looks very much like a large lawnmower. The revolving blades skim scum from the surface of the tank and convey it into either the scum pit or a trough leading to the scum pit. Some older rectangular sedimentation basins are not equipped with mechanical scum removal devices, and scum must be removed from this type of tank by means of hosing the surface until all scum is collected into one corner of the tank and then manually skimming the scum from the surface of the tank by means of hand-operated tools.

G. Raw Sludge Solids Handling. The quality of sludge removed from sedimentation tanks varies widely from plant to plant. Variations depend on many factors but the principle ones may be summerized as follows: Composition of the sewage entering the sedimentation tank including its freshness, strength, constituents and settleability; characteristics and adequacy of the settling tank; and operation of the sedimentation tank including methods of sludge removal. Table 6-1 indicates many of the characteristics of raw sludge from sedimentation basins.

TABLE 6-1

CHARACTERISTICS OF RAW SLUDGE FROM SEDIMENTATION TANKS

Quality	Description	Remarks
Physical texture	Nonuniform, lumpy	
Color	Brown	Certain industrial wastes may color the sludge or it may be dark gray or black in color if septic (see septicity below)
Density	Average solids content of 3 to 8 percent	A good quality for drawing should average 5 to 7 percent solids
Odor	Usually offensive	May have little or no odor in presence of certain industrial wastes
Volatile matter	Average range 70 to 80 percent of total dry solids	Occasionally may run as high as 85 percent or as low as 60 percent
pH	Usual range 5.5 to 6.5, average value about 6.0	Affected by industrial wastes and septicity of sludge
Total alkalinity	Range 300 to 1,000 milligrams per liter, usually 500 to 800	
Mineral or nonvolatile solids content	Around 30 percent of total dry solids	If appreciably more than 30 percent, presence of grit should be expected
Septicity	Variable	Septic raw sludge is rather common because of septic raw sewage, retention of sludge too long in tanks or poor quality overflow liquor from digestion tanks
Sludge volume	From 70 to 700 cubic feet per million gallons of sewage treated, average about 250 to 350 cubic feet per million gallons	High volumes indicate too thin a sludge is being drawn or some voluminous industrial waste is present. Low volumes indicate weak sewage, poor tank efficiency, or sludge building up in tanks

Digestibility	Normally easily digested	Nondigesting raw solids indicate harmful industrial waste such as metallic salts or fibrous matter
Grease content	Normally 15 to 20 milligrams per liter	Appreciably higher figures are indicative of industrial wastes such as waste oils or oil scouring wastes

(1) volume of sludge. Excess liquid pumped to a digester or other means of sludge treatment needlessly occupies valuable capacity. With reasonable care, the operator should be able to remove a sludge containing approximately 5 percent solids. The volume of sludge to be removed from any sedimentation basin may be estimated by the operator who measures the influent and the effluent solids, the total solids in the sludge pumped and the sewage flow. In the following equations, the method of computation is shown:

$$\text{Dry Solids Removed (lbs)} = \text{Suspended Solids Removed (mg/l)} \times 8.35 \times \text{Sewage Flow (million gal)}$$

$$\text{Wet Sludge Removed (lbs)} = \frac{\text{Dry Solids Removed (lbs)} \times 100}{\text{Percent Dry Solids in Sludge}}$$

$$\text{Wet Sludge Removed (gal)} = \frac{\text{Wet Sludge Removed (lbs)}}{8.35}$$

The use of the above equations is readily illustrated by the following example: Assume a sewage flow of 1.0 million gallons per day, a suspended solids in the influent to a sedimentation basin equal to 250 milligrams per liter, a suspended solids content in the effluent of the sedimentation basin equal to 150 milligrams per liter, and a dry solids content in the sludge of 5 percent. Assume that the operator is to determine how many gallons of wet sludge must be pumped each day.

By utilizing the equations discussed above, it is found that the dry solids removed equal 100 x 8.35 x 1.0 = 835 pounds. The wet sludge removed is equal to $\frac{835 \times 100}{5}$ = 16,700 pounds. The volume of sludge which needs to be pumped is therefore, $\frac{16,700}{835}$ = 2,000 gallons. To illustrate the effect of pumping dilute sludge, if the operator had in the above example pumped a sludge that had 3 percent rather than 5 percent solids, the resulting volume which would be required to be pumped would be 3,333 gallons which represents a 67 percent increase in the volume of sludge which must be pumped and means that raw sludge handling facilities would actually be handling 67 percent more liquid than would be necessary. Figure 6-9 indicates the wide variation in sludge volume with a small change in the concentration of solids graphically.

(2) sludge pumping and pumping equipment. The proper solids concentration of sludge pumped from primary settling basins will vary from plant to plant but will generally be from 5 to 8 percent. The sludge pumped from secondary settling basins is much more dilute, and the pumpage is usually dictated by the requirements of the secondary treatment units involved.

Pumping may be continuous or intermittent. When several pumps are used, one pump may withdraw sludge from one hopper while another pump withdraws from another. However, a single pump should not withdraw sludge from more than one hopper at any one time since differences in piping friction and densities and viscosities of the sludge generally always cause more sludge to be withdrawn from one hopper than from the other. Preferably, pumping should be done for short durations at frequent intervals rather than for long periods at infrequent intervals.

In very small treatment plants with operating personnel on duty only part of the time, sludge is sometimes pumped only once or twice a day; however, in larger plants with operating personnel on

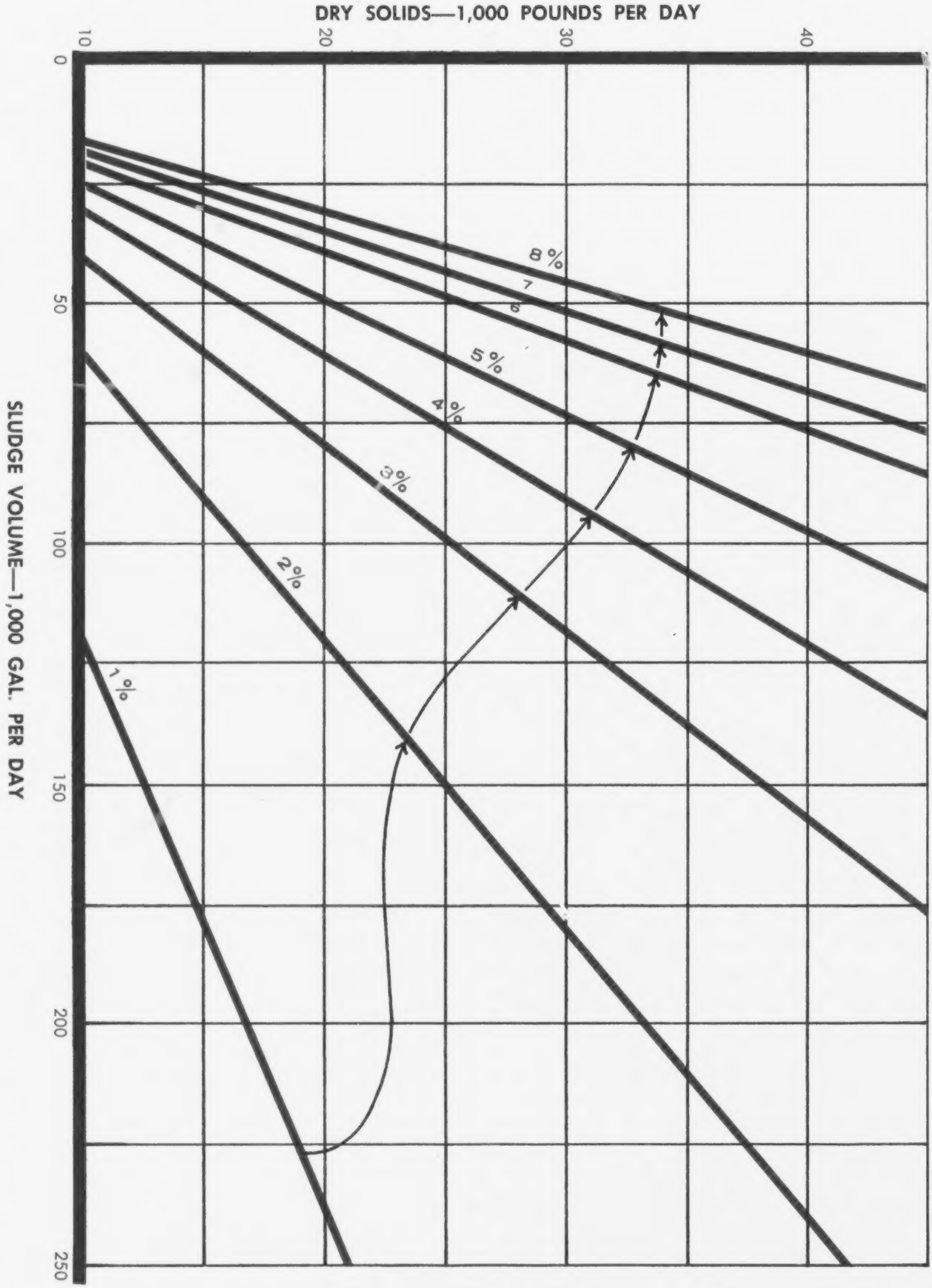


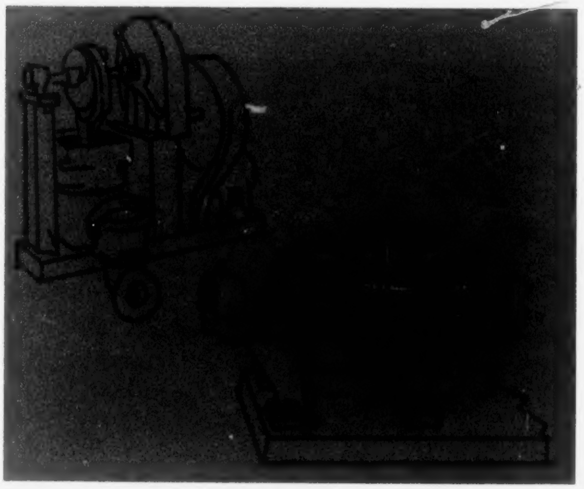
Figure 6-9 Effect of solid concentration on required sludge volume

duty at all times, sludge should be pumped at least hourly. Sludge should be pumped only as fast as it can flow to the hopper. Pumping sludge at rates faster than the sludge can be scraped or moved to a hopper, will simply result in pumping more and more liquid and less and less solids.

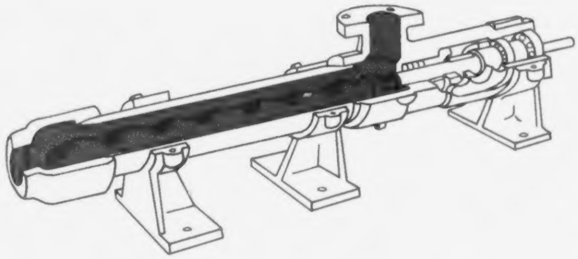
Several types of pumps are in common use for the pumping of raw sludge from sedimentation basins to either digesters or sludge conditioning devices. Probably the most common type of pump used today is the so-called piston pump. The piston pump simply consists of a cylinder fitted with a moving piston which alternately moves up and down within the cylinder thus causing a pulsating pumping action. Piston pumps are usually equipped with one or more ball check valves on both the inlet and the discharge end of the pump. As the piston moves up in its cylinder, the discharge check valve closes and the intake check valve opens, thus allowing sludge to be drawn into the cylinder. On the downward stroke of the piston, the discharge check valve opens and the intake check valve closes thus allowing the sludge drawn into the cylinder on the intake stroke to be forced out by the downward action of the piston. Piston type sludge pumps are commonly used in various sizes and may consist of more than one set of cylinders and pistons connected to a common drivehead. Multiple piston and cylinder setups are called duplex or triplex piston pumps.

Another type of positive displacement pump commonly used for removal of raw sludge from sedimentation basins, is referred to as the progressing cavity type pump. This type pump, also commonly called a Moyno pump, consists of a rotating deformed metal shaft surrounded by a stationary synthetic rubber boot. As the metal shaft rotates, openings between the rotating shaft and the stationary boot are alternately opened and then closed in a progressive motion which causes sludge to be forced along the axis of the pump to the discharge end.

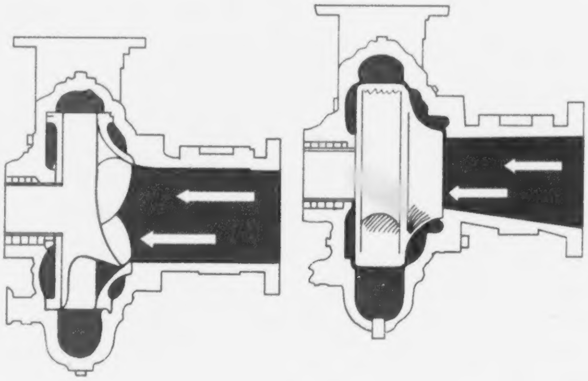
A few plants utilize centrifugal type pumps to pump raw sludge. These are usually of the recessed impeller design in which the impeller vanes are so constructed as to remain clear of the fluid actually being pumped. A common example is the open impeller pumping unit as shown in the illustration in Figure 6-12.



PLUNGER AND CENTRIFUGAL TYPE PUMPS
Figure (6-10)



MOYNO TYPE PUMP
Figure (6-11)



CENTRIFUGAL TYPE PUMP
Figure (6-12)

In some cases sludge is removed from sedimentation basin hoppers by means of an airlift pump. An airlift pump simply consists of a vertical length of pipe inserted at a point near the bottom of a sludge hopper and rising upwards. A jet of high velocity air is introduced into this pipe. The velocity of air rising up the suction pipe causes fluid to be swept into the suction pipe and pumped upwards. The use of airlift devices for the pumping of raw sludge, while once at least fairly common, has today become very infrequent and many plants which were originally designed with this type of pumping equipment have since been converted to the use of more positive pumping means.

(3) raw sludge thickening. Many larger waste treatment plants provide equipment to thicken either raw sludge or combined raw and secondary sludges prior to further treatment of the sludges. The purpose of sludge thickening is of course to concentrate the sludge solids into as thick a mixture as possible. This concentration results in several advantages. One major advantage is that sludge thickening concentrates all of the sludge solids into a much lesser volume of liquid and therefore much less liquid needs to be pumped into succeeding sludge treatment stages; another major advantage is that succeeding sludge treatment units need not be sized to handle all of the excess liquid and may therefore in some instances be smaller or at least more economical to operate.

There are essentially two major types of sludge thickening in use in present day waste treatment plants. These two types of sludge thickening may be termed gravity thickening and flotation thickening.

Gravity thickening is probably the most common type of sludge thickening practiced in instances where raw sludge is involved. Gravity thickeners are constructed much like circular sedimentation basins and are equipped with similar types of mechanisms. In general, gravity thickeners tend to be deeper than sedimentation basins and usually equipped with more steeply sloping bottoms. Gravity sludge thickeners are generally designed on the basis of a solids loading criteria versus available surface area of the thickening unit. There is considerable disagreement among design engineers, equipment manufacturers, and regulatory agencies as to the upper limits of acceptable loading ranges for gravity sludge thickeners. However, in most cases, gravity sludge thickeners are not loaded at a rate of more than 20 pounds of dry solids per square foot of surface area per day. The maximum loading at which any given gravity type sludge thickener will operate must be determined either by testing the sludge to be thickened or by experimentation with the thickening unit after its installation.

Gravity sludge thickeners operate by introducing the sludge to be thickened along with a source of oxygenated, reasonably solids-free water such as secondary plant effluent or in some cases, aerated primary clarifier effluent. This mixture is introduced through a center feedwell in most gravity type thickening units and the sludge tends to settle to the bottom in a manner similar to the action of a sedimentation basin. Attached to the rotating rake arms in most gravity thickeners are a system of vertical pickets which tend to stir the sludge slowly thus promoting contact between sludge particles and result in an increase in sludge particle size. The steeply sloping floor and large sludge hopper common to most types of gravity thickeners, promote the build-up of a much more concentrated sludge layer on the bottom of the thickener, and the weight of water above the thickened sludge layer being deeper than in the normal clarifier tends to compact the thickened sludge layer even further. As a net result, most gravity type thickeners, when operating on a waste amenable to this type of thickening, are able to produce solids contents of 8 percent or greater.

As mentioned previously, gravity type sludge thickeners need to have a source of oxygenated water for their proper operation. Because sludge detention times in gravity type thickeners may be significant, it is necessary that oxygen be available so that any biological action which occurs in sludge thickeners will be aerobic rather than anaerobic in nature. If sufficient oxygenated water is not supplied, anaerobic decomposition may take place with resultant release of obnoxious odors as well as a floating sludge blanket being created because of attachment of minute gas bubbles to sludge particles. Even in properly operating gravity type sludge thickening units it is likely that at times a rather dense surface scum layer will develop. This scum layer should, of course, be skimmed from the surface of the tank and pumped away in much the same manner as the thickened sludge from the bottom hopper. Nearly all gravity sludge thickening devices are equipped with a surface skimmer which automatically skims such surface scums and deposits them in a scum well for further handling. Many times, plant operators may find that the single scum skimming sweep provided on most gravity type sludge thickeners, does not remove surface scums at a rapid enough rate in order to assure reasonable effluent characteristics. The addition of a second skimming sweep, has many times been found to be quite effective in overcoming this problem, and in most cases a second sweep may be added without making major modification to existing units.

It should be noted that many sludge combinations do not react very satisfactorily to gravity thickening. Particularily, it appears that mixtures of raw sludge plus waste activated sludge, are not amenable to gravity thickening in most cases; and it may well be that satisfactory operations will be very difficult to achieve in plants having this problem. Mixtures of raw sludge and secondary sludge from biological filters, tend to gravity thicken fairly well in most instances; however, certain types of industrial wastes such as those from food processing industries may also cause operation of gravity thickeners to be difficult. In some cases where difficulty with operation of gravity type thickeners has been experienced, the addition of small amounts of chemical flocculation aids (sometimes referred to as polymers or polyelectrolytes) has proven to be successful. These chemical substances are manufactured by a number of chemical supply firms, including the Dow Chemical Company, the American Cyanamid Company, and the Rohm and Haas Company Inc. Operators who continually experience difficulty with operation of gravity sludge thickening units might be well advised to investigate the use of chemical thickening aids to improve their process operation.

In some cases sludge thickening and primary sedimentation are carried out in the same physical unit. For example the Eimco Corporation makes equipment for a combination primary sedimentation basin and sludge thickener. In this type of design the primary sedimentation basin is constructed with a deeper center section. The deeper center section is equipped with the same type of raking and stirring devices normally used in gravity thickeners and the shallow outer sections are equipped with the same type of equipment normally used in primary sedimentation basins. Figure 6-13 illustrates a typical gravity sludge thickener.

The second major type of sludge thickening in current use today is termed flotation thickening. Flotation thickening is not normally used for primary sludges as produced in primary sedimentation since this type of sludge can usually be handled more economically by the gravity type thickeners. The use of flotation thickeners has, however, become quite popular where difficult to thicken secondary sludge such as waste activated sludge or secondary sludge from biological filtration is present. A number of manufacturers including the Chain Belt Company, Eimco Corporation, and Komline Sanderson Company, produce equipment used for flotation thickening.

Basically the process consists of introducing the sludge flow into a chamber wherein it is intimately mixed with a source of water which has been exposed to quite high pressures and in which large amounts of air have been dissolved. Under the high pressures involved, a considerable amount of air actually goes into solution in the high pressure water. When this high pressure water and the sludge to be thickened are mixed together and the pressure is released, the dissolved air suddenly becomes subject to only slightly greater than atmospheric pressure and this air is released in the form of millions of very tiny air bubbles. These air bubbles tend to attach themselves to particles of sludge thus causing the sludge to immediately rise to the surface of the flotation thickening unit. The sludge is then scraped by skimmers from the surface of the thickening unit into a chamber from which it can be pumped or otherwise removed for further treatment. Most flotation thickeners are also equipped with a mechanism for collecting sludge which settles in the bottom of the thickening unit. Normally, very little organic matter settles to the bottom of flotation thickeners; however, in some cases a considerable amount of grit and large solid particles may be collected on the bottom of the thickening unit. These materials are usually scraped to one end of the thickening unit from which they may be periodically pumped along with the thickened "float" for further treatment.

Generally speaking, flotation thickeners may be loaded at much higher rates than gravity thickeners and loading rates of as high as 50 pounds of dry solids per square foot of thickener area per day are in usage today. As is the case with gravity thickening units, various manufacturers disagree as to optimum loading concentrations. Flotation thickening units have proven to be quite successful in thickening what might otherwise be termed to be difficult to thicken sludges, and they are becoming more and more widely used, particularly in activated

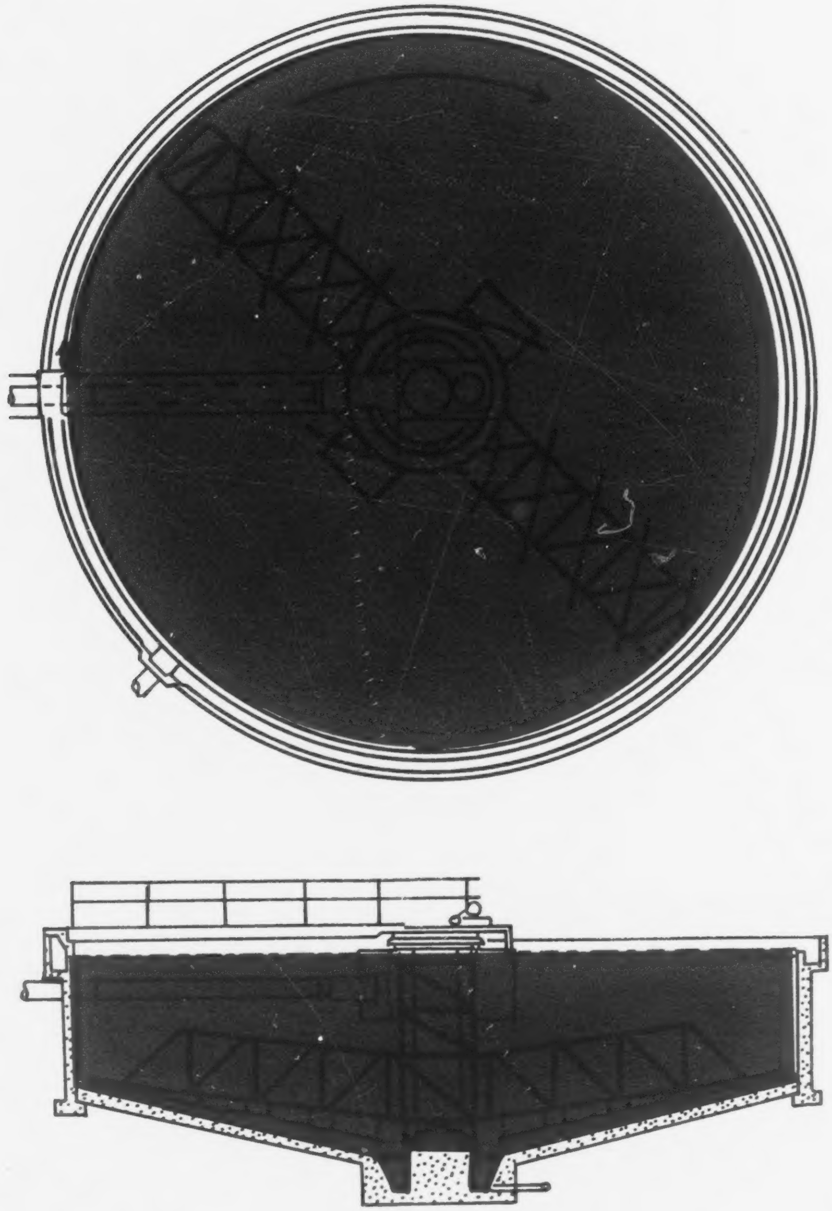


Figure (6-13)
TYPICAL GRAVITY SLUDGE THICKENER

sludge plants or in treatment plants serving large industrial waste contributors.

As is the case with gravity thickening units, it is sometimes necessary to add chemical thickening aids in order to achieve satisfactory operation of flotation units. Most manufacturers of flotation thickening equipment are well equipped to assist operators in helping to determine the necessity and the selection of coagulant aids which may prove to be advantageous in flotation thickener operation. Figure 6-14 illustrates a typical flotation thickener.

(4) sludge filtration. Occasionally, larger waste treatment plants are equipped with sludge filtration equipment to further dewater either primary sludge or a combination of primary and secondary sludges.

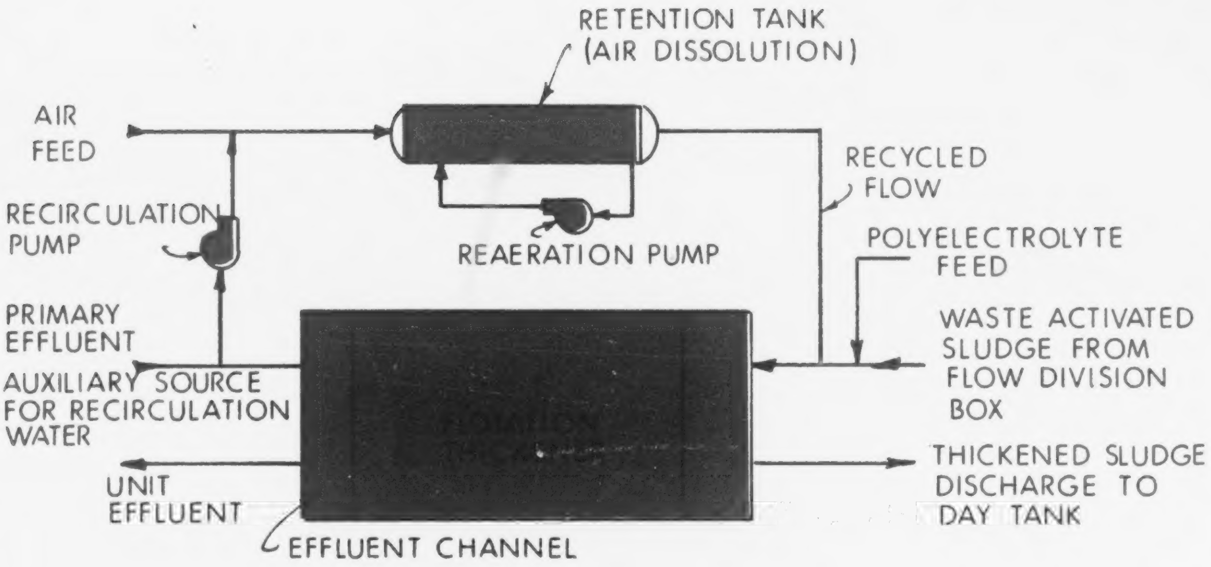
There are basically two types of sludge filtration equipment in common usage today; these two types of equipment, for the most part, vary only in the type of media used for filtering of the sludges.

Most older sludge filters, as well as some of the newer equipment utilize a continuous cloth belt which is rotated over a large perforated drum as a filtering media. Various types of cloth may be used depending upon the characteristics of the sludge to be filtered. The earliest sludge filtration equipment utilized either animal or vegetable fibers such as cotton or wool woven into a belt. More modern filtration equipment tends to be equipped with synthetic cloth belts such as dacron, nylon and various other synthetic cloths. In essence the cloth belt sludge filter consists of a large tank into which preconditioned sludge is held. A large drum over which the cloth belt rides is partially immersed in this sludge material. The drum is rotated slowly and is subjected to a partial vacuum which tends to pull water and soluble materials through the cloth belt while the solid sludge particles are trapped on the surface of the belt. As the drum rotates out of the sludge holding pan, additional dewatering takes place and the sludge solids cake is held to the surface of the belt by the combination of the applied vacuum and the tendency of the sludge particles to mesh into the surface of the cloth fibers. By means of a system of rollers and scrappers, the cloth belt moves off the surface of the drum and over a small diameter roller which tends to break the sludge cake free of the moving belt. Adjustable scrappers are provided to help scrape the discharged cake free of the belt. Usually a system of water sprays may be incorporated to help flush the belt clean of solids which may have been trapped within the fibers. The continuous belt then returns to the surface of the rotating drum to be again dipped into the sludge holding vat to pick up additional sludge.

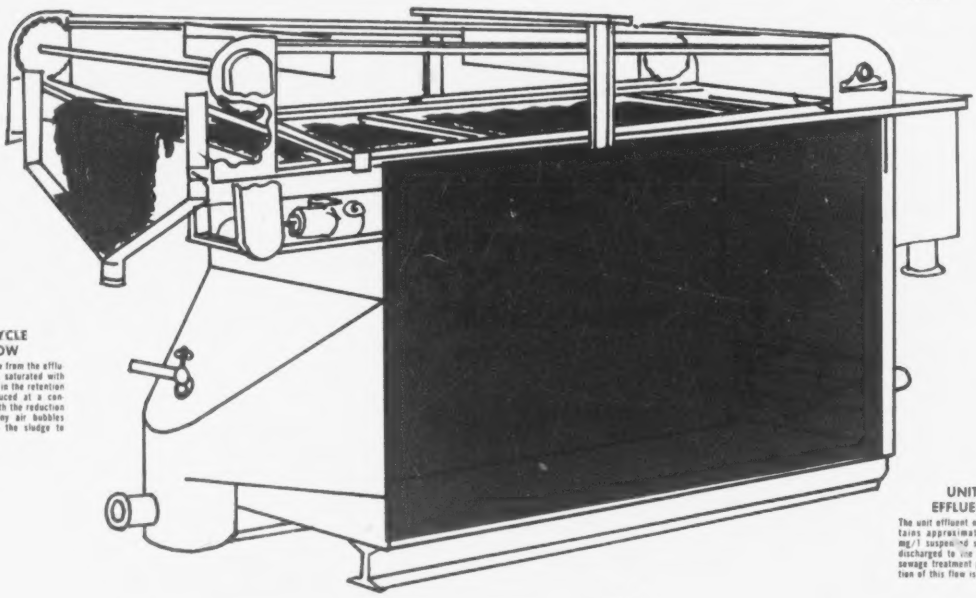
The earliest sludge filtration equipment was quite sensitive to the condition of the sludge to be filtered and accordingly in most cases a sludge preconditioning tank was incorporated into the design of the sludge filter. The sludge preconditioning tank usually consisted of a rotating drum into which the sludge to be filtered as well as certain chemicals were intimately mixed. Commonly, ferric chloride and lime were used to help precondition the sludge prior to filtration. Other problems associated with early vacuum filters included the fact that the cloth belts made of vegetable or animal fibers did not prove to be particularly satisfactory with respect to belt life and also tended to plug or clog rather easily, thus requiring complete shutdown of the equipment for cleaning purposes. Belt tension was particularly important and it was also necessary to pay close attention to the unit in order to assure that the belt tracked evenly over the surface of the drum. Later models of belt-equipped sludge filters utilizing synthetic cloth media, have overcome the problems associated with the animal or vegetable fiber belts and in addition have been designed with automatic belt tensioners and belt centering devices which require much less operator maintenance in order to keep them in satisfactory operating condition.

The other type of media commonly used on sludge filters consists of coiled stainless steel springs rotating in grooves on the filter drum which takes the place of the cloth media. Operation of this type of filter is essentially the same as for a cloth filter; however, automatic tensioning and centering devices are not required because of the self centering action of the stainless steel springs on the grooves supplied on the filter drum.

Either type of sludge filtration equipment is capable of producing solids cakes in the range of 20 to 35 percent solids depending on the type and condition of sludge being filtered. In most cases, the filtrate, when the machines are being properly operated, can be kept relatively free of solids. Frequently where sludge filters are used, the sludge cake is disposed of either by burial or by incineration and in all cases the filtrate must be returned for complete retreatment through the waste treatment plant. Advantages of both types of sludge filtration equipment include rather low mainte-


RETENTION TANK
(AIR DISSOLUTION)
AIR
FEED
RECYCLED
FLOW
RECIRCULATION
PUMP
REAERATION PUMP
POLYELECTROLYTE
FEED
PRIMARY
EFFLUENT
WASTE ACTIVATED
SLUDGE FROM
FLOW DIVISION
BOX
AUXILIARY SOURCE
FOR RECIRCULATION
WATER
THICKENED SLUDGE
DISCHARGE TO
DAY TANK
UNIT
EFFLUENT
EFFLUENT CHANNEL

SCHEMATIC FLOW DIAGRAM



THICKENED SLUDGE DISCHARGE
This thickened sludge is discharged to a sump from which it is pumped to a vacuum filter or digester. Sludge concentrations of 4-6% can be expected with most sludges.

THICKENED SLUDGE ZONE
This thickened sludge creates a zone in the upper portion of the flotation unit and compacts and forces the surface of the sludge above the water level where it is removed by the sludge removal blades.

SLUDGE REMOVAL MECHANISM
The sludge removal mechanism consists of chains and skimming flights, sprockets and variable speed drive. The speed of the flights is varied to allow maximum concentration of sludge and minimum water carry-over.

ADJUSTABLE WEIR
This adjustable weir controls the liquid level within the flotation unit and the depth of penetration of the sludge skimming blades.

RECYCLE FLOW
The recycle flow from the effluent of the unit, saturated with air at 50-70 psi in the retention tank, is introduced at a controlled rate. With the reduction in pressure, tiny air bubbles form and float the sludge to the surface.

UNIT EFFLUENT
The unit effluent normally contains approximately 50-250 mg/1 suspended solids and is discharged to the head of the sewage treatment plant. A portion of this flow is recycled.

FLOW ZONE
In the flow zone the sludge particles are separated from the water as they enter the thickened sludge zone. A properly operating flotation unit effects reliable and positive separation with minimum attention.

SLUDGE FEED
Waste sludge from the activated sludge system is conditioned with flotation aids and fed to the unit at a relatively constant rate.

NOTE. Recirculation pump, re-aeration pump and retention tank are not shown. Also, the bottom sludge collectors or hoppers are not shown.

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Komline Sanderson Inc.

Figure (6-14)
TYPICAL FLOTATION SLUDGE THICKENER

nance cost and ease of operation as well as relative freedom from breakdown. Disadvantages include rather high power requirements for the vacuum pumps, high chemical costs and in some cases a necessity for considerable testing and experimentation in order to determine which conditioning chemicals are best suited to the particular sludge to be filtered. Another disadvantage is that the sludge filtration process will often give rise to offensive odors particularly if septic or unstable sludges are to be dewatered by filtration. Figure 6-15 illustrates a typical sludge vacuum filter.

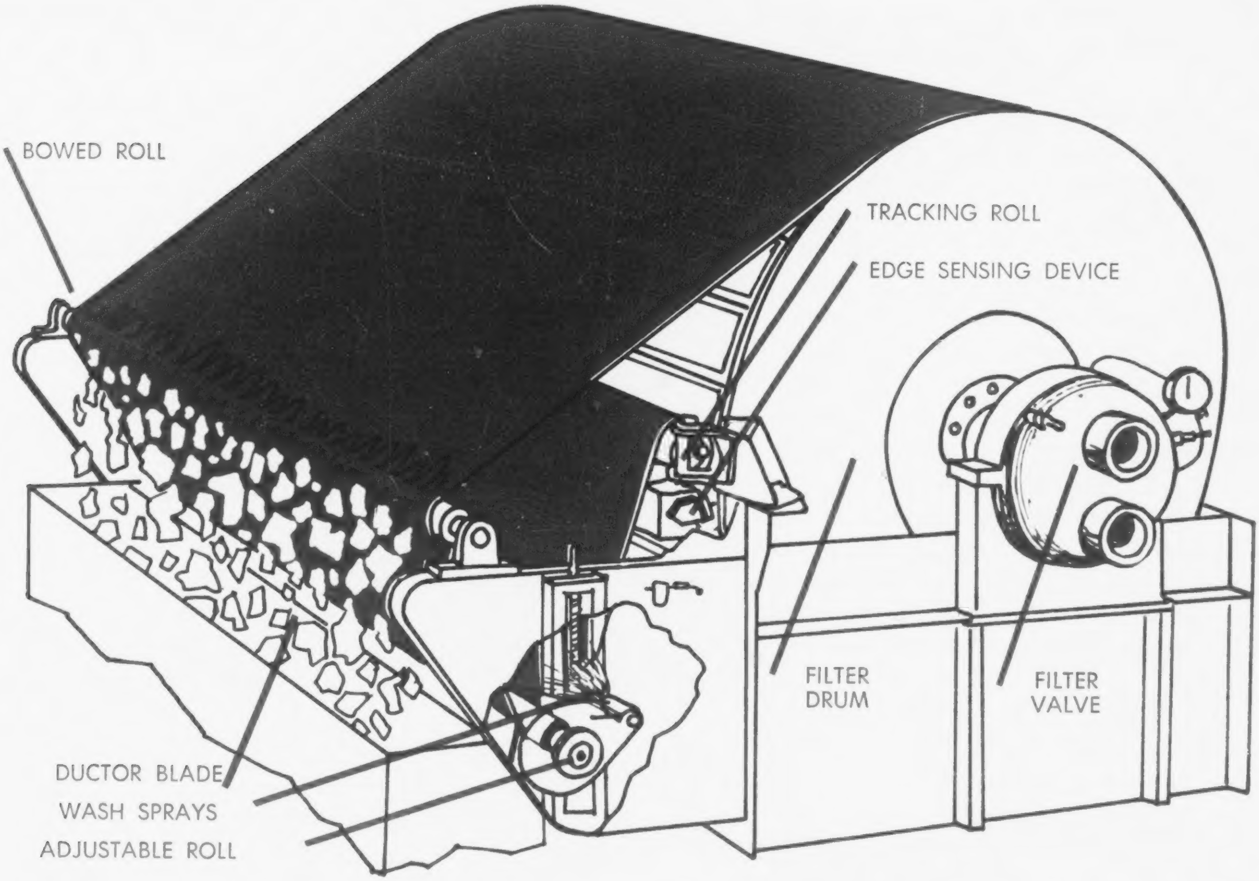
BOWED ROLL
TRACKING ROLL
EDGE SENSING DEVICE
FILTER DRUM
FILTER VALVE
DUCTOR BLADE
WASH SPRAYS
ADJUSTABLE ROLL

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Figure (6-15)
TYPICAL VACUUM FILTER

(5) sludge centrifugation. Another method of dewatering sludge solids which is apparently increasing in its usage is the use of continuous flow solid bowl centrifuges which separate solids from their conveying liquids by means of differences in specific gravity and the use of centrifugal force. The equipment used for this purpose is generally termed continuous flow solid bowl centrifuge. This device consists of six main parts as follows: a drive motor which drives a gear reduction unit usually by means of V-belts; a heavy vibration isolating base; a set of two supports which are mounted on the base and which hold the bearings for the rotating elements; an outer stationary cover or case which surrounds the rotating element; a rotating cylindrically-shaped solid bowl which has a sloping cone at the discharge end; and a rotating screw conveyor which rotates inside the solid bowl. In operation, a solids-containing liquid is forced into the rotating solid bowl by means of an influent pipe. The solids-containing liquid discharged from the influent pipe is spun rapidly by the rotating solid bowl and the solids fraction of the influent being of higher specific gravity is preferentially thrown to the outside of the bowl while the liquid, having a lower specific gravity, remains as an inner layer inside of the solids layer. The rotating conveyor or scroll, as it is often termed, is caused to rotate in the same direction as the solid bowl, but at a slightly different speed. This difference in speeds causes the rotating scroll to actually screw the solids portion of the waste towards the solids discharge end of the rotating solids bowl, up the incline formed by the cone-shaped section and through discharge ports. The liquid which has been separated from the solids is usually called centrate and is discharged either over a weir or by means of a scoop arrangement, depending on the type of centrifuge involved.

Basically, two flow patterns are in current usage today for sludge handling centrifuges. In the one case, solids are moved to the discharge end of the centrifuge in the same direction as the liquid. This type of machine is called a concurrent flow machine. In the other type of equipment, the solids are moved in one direction while the centrate moves in the opposite direction. This type of machine is termed a countercurrent flow centrifuge. The concurrent flow machine, being relatively new, is not at present widely used; however, it is to be expected that its usage will increase.

The rotating elements in sludge centrifuges represent considerable weight and accordingly special electric motors and electric controls are often required in order to start the machine. Because of the large rotating mass, centrifuges once set in motion tend to remain so for considerable periods of time even after power has been shut off. As may be imagined, because of the high rotational speeds, should an unbalanced load occur within the rotating elements, tremendous vibrational forces would be set up. Accordingly, the design of bases and supports for centrifuges must be such as to ensure that these vibrations can be safely handled. Because of the difference in rotating speed between the scroll and the solid bowl, a shearing force is created between the surfaces of the scroll and the solid bowl. This shearing force produces wear on the tips of the scroll and the rate of wear can be extremely rapid if gritty materials such as silica sand are present in the sludge being centrifuged. Scrolls are normally hard faced with special materials designed to resist wear such as stellite. Even when faced with the hardest known materials, conveyor scrolls may have a relatively short life span. The design of most centrifuges is such, however, that the conveyor scrolls may be refaced by applying new surfaces by arc-welding with stellite or other special rods. When conveyor scrolls are refaced it is necessary that they be checked for balance before they are again put into operation in order to assure that unbalanced loads within the machine will not occur.

Sludge centrifuges have the advantages of being relatively simple to operate and of requiring little operator attention once in operation. Disadvantages include high maintenance cost, high power requirements, a sludge cake normally containing more water than would be present in a well-operated filter sludge cake and a centrate which often contains a high percentage of very fine solids which cannot be centrifuged from the system.

Centrifuges require probably less floor space than do sludge filters and since the use of chemical or sludge conditioning agents is sometimes not required, the overall cost of sludge dewatering by the use of centrifuge as compared to sludge filters may make the centrifuge the most economical choice. As is the case with vacuum filters, the sludge cake discharged by centrifuges is normally either disposed of by burial or is incinerated. The centrate or liquid portion of the feed to the centrifuge must, of course, be returned to the treatment works for complete retreatment. Figure 6-16 illustrates a typical sludge centrifuge.

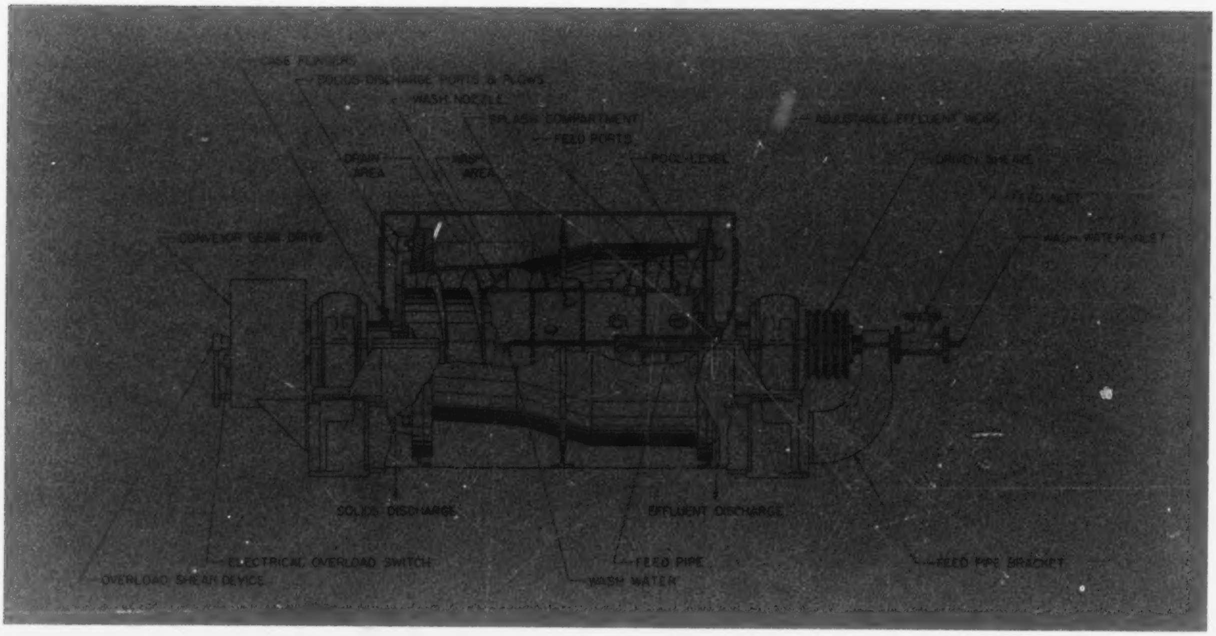
CASE PLOWS
SOLIDS DISCHARGE PORTS & PLOWS
WASH NOZZLE
SPLASH COMPARTMENT
FEED PORTS
ADJUSTABLE EFFLUENT WEIR
DRAIN AREA
WASH AREA
POOL LEVEL
DRIVEN SHEAVE
FEED INLET
CONVEYOR GEAR DRIVE
WASH WATER INLET
SOLIDS DISCHARGE
EFFLUENT DISCHARGE
ELECTRICAL OVERLOAD SWITCH
OVERLOAD SHEAR DEVICE
FEED PIPE
WASH WATER
FEED PIPE BRACKET

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Figure (6-16)
TYPICAL SLUDGE CENTRIFUGE

(6) sludge incineration. Because of the difficulty in disposing of sludge solids, either in the raw form or after digestion, many large treatment plants have turned to sludge incineration as a method of reducing the volume of solid waste for disposal. Since raw sludge solids usually contain 70 to 80 percent volatile material it can be seen that incineration can indeed offer a method of reducing the volume of solids to be disposed of by a factor of from 5 to 10 times. Basically, sludge incinerators are simply large furnaces in which sludge solids are combusted with auxiliary fuel as is needed. The end products of the incineration process are various gases, water vapor, and ash. Because of the rather high temperature at which all sludge incinerators operate, it is advantageous to reduce the water content of the sludge as much as possible before incineration. This is done because each pound of water which enters the incinerator must be heated to form steam and the resulting steam heated to the same temperature as the discharged gases from the incinerator. The bulk of this heat cannot be recovered and represents a considerable expenditure in auxiliary fuel. In many cases, where raw primary sludges are incinerated, it is possible to dewater the sludge to a point such that, once an incinerator is started, no auxiliary fuel is required in order to continue the combustion process. In this case the sludge itself provides all the fuel necessary for its own incineration. In other cases where digested sludge or where combinations of primary and secondary sludges are to be incinerated, it is usually necessary to supply considerable auxiliary fuel in order to support the combustion process.

Two main types of sludge incineration are in current usage today. These two main types may be referred to as the wet combustion process and the dry combustion process.

There are very few wet combustion process sludge incinerators in use today, and none of these are located in the Pacific Northwest. In spite of this it may be interesting to at least briefly discuss this process since it is possible that the process may become more popular in the future. In the wet combustion process, liquid sludges are subjected to high pressures and high temperatures within a closed reactor. At the high temperatures and pressures involved, a rapid oxidation occurs which converts the volatile sludge solids into ash with a resultant liberation of heat. This oxidation occurs without the actual presence of a flame and so probably should not be termed combustion. The entire process might be likened to the rusting of a ferrous metal under water. When iron rusts, it is said to have oxidized. The oxidation of iron liberates a considerable amount of heat; however, normally the oxidation or rusting process is so slow that the heat generated goes unnoticed. In the case of the wet oxidation process, however, the speed with which volatile solids are caused to react is increased greatly by the action of high temperatures and pressures and in this case the heat liberated is readily noticeable and is in fact, reclaimed to help support the entire process. In summary, it should be noted that the wet oxidation process is extremely complicated and utilizes a great deal of rather specialized equipment for its control and operation.

The second major type of sludge incineration in use today is the dry combustion type. Equipment for the dry combustion of sludge may be one of three main types; flash process, multiple hearth furnace, or fluidized bed reactor.

In the flash combustion system, sludge to be incinerated is first passed through a combination fluffer-dryer in which it is pulverized and dried into fine dry particles. Heat for this drying is usually obtained by passing the stack gases from the burner through the dryer section. From the dryer section the dry sludge is conveyed into a combustion chamber where it is immediately ignited and burned to ash in a very short period of time, hence the equipment gets its name of flash incineration. The ash produced in the flash incineration process is moved out of the combustion chamber by the high velocity gases and is separated from the gas stream either by means of cyclone separators or wet scrubbers.

The second and probably most widely used at present type of dry combustion sludge incineration equipment is termed the multiple hearth furnace. Multiple hearth furnaces, in general consist of a cylindrical shell having usually three or more burning hearths stacked vertically one over the other. In operation, the wet sludge cake is deposited by means of conveyor system onto the upper hearth of the furnace. Rotating arms called rabble arms and equipped with teeth convey the wet sludge around the floor of the topmost hearth and a stream of hot gases from combustion occurring in underlying hearths is passed up to the upper hearth, thus drying the sludge solids. As the sludge solids are rabbled around the top hearth, they are dried and finally fall through a hole in the hearth to the next succeeding hearth underneath. Here the process is repeated until the sludge passes through the entire number of hearths. Any of the hearths may be fired by means of burners which are fueled either by oil or gas. Because of the volume contained within the usual multiple hearth furnace, air and gas velocities are such that appreciable amounts of ashes are not carried from the furnace to the stack but instead exit from the bottom hearth into a conveying system for ultimate disposal. The small amount of ash and particulate matter contained in the gaseous discharge from the multiple hearth furnace may be removed either by wet or dry scrubbing. Multiple hearth equipment, of course, takes its name from the fact that it consists of a number of hearths stacked in a vertical configuration and equipped with a common mechanical rabbling device. Figure 6-17 illustrates a typical multiple hearth furnace.

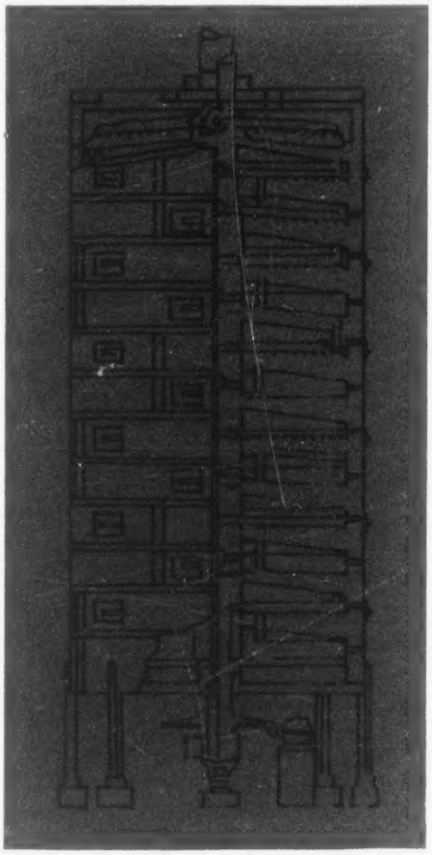

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Figure (6-17)
TYPICAL MULTIPLE HEARTH
FURNACE

The third type of dry combustion process is broadly termed the fluidized reactor. In this process, wet sludge cake is introduced into a reactor usually partially filled with heated sand. The heated sand is kept in a fluid-like suspension by the velocity of high volumes of air blown through the reactor. In its semi-suspended condition, the sand actually acts as a fluid and it is into this heated fluidized sand media that the wet sludge cake is introduced. Under the temperature conditions present within the reactor, combustion of the wet sludge cake is practically instantaneous with the heat thus liberated going toward helping to support combustion temperatures within the reactor. The ash created by the combustion is carried out of the reactor by the velocity of gas flowing through the reactor to be separated by cyclones or wet scrubbers. Exit temperature from the fluid bed reactor is usually on the order of approximately 1,400 degrees F.; accordingly, the off gases from the reactor represent a considerable investment in available heat. For this reason these off gases are usually passed through a heat exchanger before being discharged to the atmosphere. The heat thus recaptured from the off gases is used to heat the large volumes of pressurized air required to fluidize the sand bed. Combustion within the fluidized reactor is extremely efficient and were it not for the necessity of maintaining such high temperatures within the reactor, this method of sludge incineration would be the most efficient of all the methods herein discussed. Because of the inability to recover all of the heat from the off gases, however, the entire process is probably no more efficient than any of the other sludge incineration processes with respect to auxiliary fuel requirements. Figure 6-18 illustrates a typical fluidized reactor.

All of the various sludge incineration processes have the common advantage that the volume of solids to be ultimately disposed of is considerably reduced, that the volatile matter destroyed is simply converted into, for the most part, harmless gases which can be safely discharged to the atmosphere. Operation of all of the incineration units is however, quite expensive and does require a considerable amount of operating attention and maintenance. Because of this reason, the use of sludge incineration has, at least until the present, been normally associated only with rather large treatment plants.

There are of course exceptions to this generalized statement and the fluidized reactor presently in operation at the City of Lynnwood, Washington is an example of such an exception. It is undoubtedly true that in the future there will be more and more sludge incineration units put into operation as it becomes more and more difficult to dispose of either raw or digested sludge solids. At least one major manufacturing concern at the present, has announced plans to begin marketing small package sludge incineration units which can be used on even very small treatment plants.

(7) treatment of sludge solids by digestion. Most present-day treatment plants effect final treatment of the solids removed from the waste flows by means of digestion. Two types of digestion are in current usage today, these being anaerobic and aerobic digestion. Both of these processes will be described in much greater detail in a later section of this chapter; however mention is made of the processes here in order to complete the entire picture of solids handling.

Anaerobic sludge digestion is a process in which controlled biological decomposition of volatile sludge solids occurs under anaerobic conditions. The process takes place in several distinct phases each of which occurs simultaneously with succeeding phases in a single reaction vessel commonly called a digester. End products of the anaerobic sludge digestion process are water, carbon dioxide, methane gas and relatively biologically inert solids commonly referred to as humus. The entire anaerobic sludge digestion must take place under carefully controlled conditions which will be more thoroughly discussed in a later section of this chapter.

The second method of sludge digestion is termed aerobic sludge digestion and may be defined as the biological degradation of sludge solids under aerobic conditions. Aerobic sludge digestion generally takes place in open basins or lagoons which are constantly mixed and aerated by various types of aeration devices. End products of this type of digestion are water, carbon dioxide, and the relatively biologically inert solids fraction which is also generally termed humus. The aerobic digestion process will be discussed in much greater detail in a later section of this chapter.

H. Raw or Chemically Treated Sludge Disposal. As previously discussed, in some cases, raw or chemically treated sludge is disposed of without further treatment after being dewatered by means of vacuum filters or centrifuges. This type of sludge, even though it may contain considerable amounts of conditioning chemicals, is still very readily decomposable by the action of bacteria and therefore may not be disposed of on the surface of the land without creating nuisances. In most instances, the only satisfactory method of disposing of dewatered raw sludges is to bury the material in locations where groundwaters will not be adversely

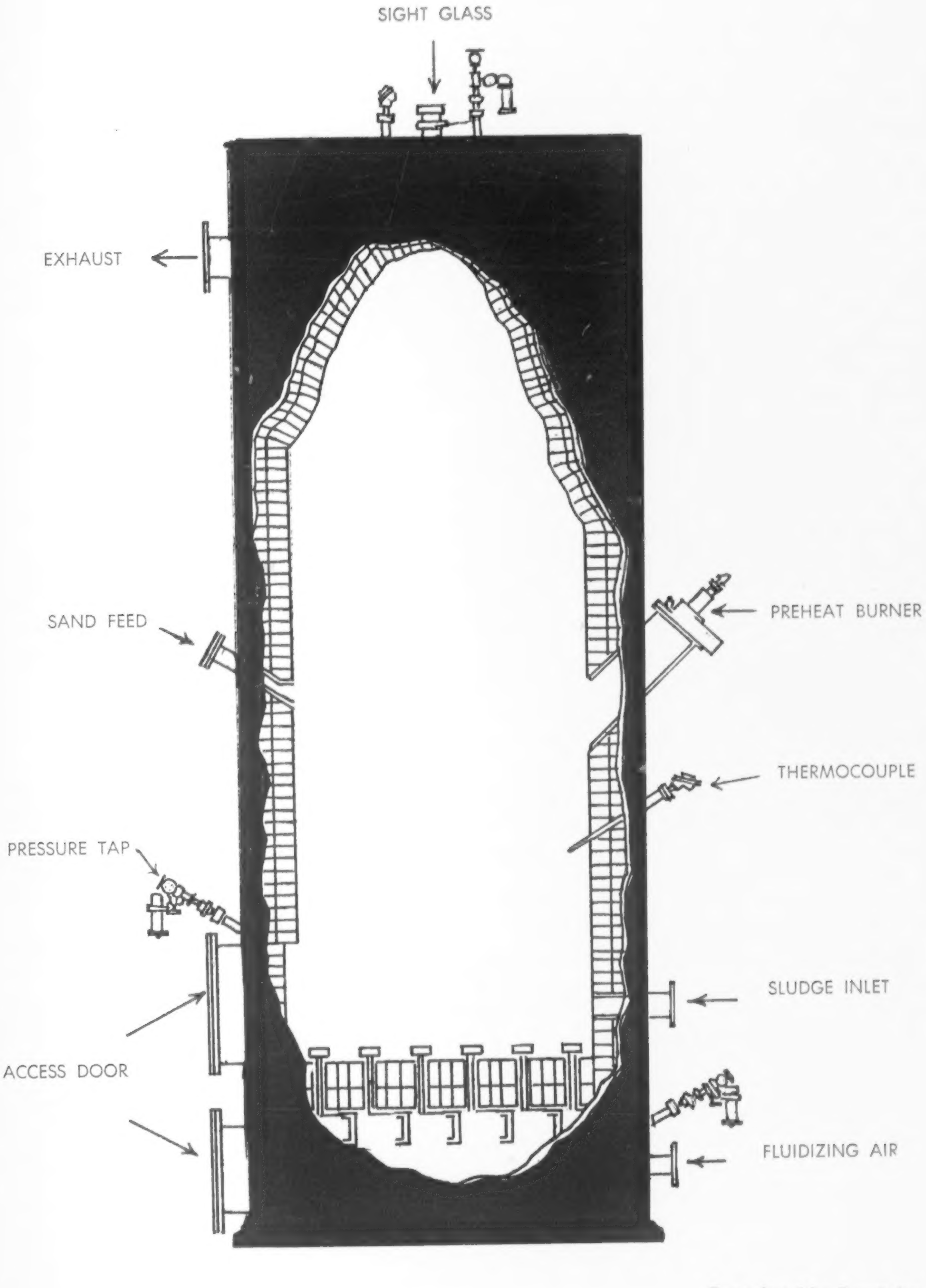
SIGHT GLASS
EXHAUST
SAND FEED
PREHEAT BURNER
THERMOCOUPLE
PRESSURE TAP
SLUDGE INLET
ACCESS DOOR
FLUIDIZING AIR

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Figure (6-18)
TYPICAL FLUIDIZED REACTOR

affected and to provide at least a 15-inch cover of earth over the buried sludge cake. Disposal locations, of course, must be very carefully chosen so as to protect underlying groundwater strata as well as to provide safeguards against the scouring of the earth cover by the action of surface water.

Some large metropolitan areas which are located on seacoasts have practiced solids disposal by barging the dewatered solids out to sea for ocean disposal. This practice has very little to commend it however; and regulatory agencies, both State and Federal, look with disfavor upon the practice.

I. Digested Sludge Solids Handling.

(1) general. Digested sludge solids may be dried on sludge drying beds, stored either permanently or temporarily in lagoons, dewatered by filtration or centrifuging, heat-dried and ground, or incinerated.

(2) sludge drying beds. Sludge drying beds are the most commonly used means for dewatering sludges. This is particularly true for small to medium plants where there is ample area and where there is a good demand for sludge as a soil conditioner. Drying on sand beds reduces the moisture content of well-digested sludge from a normal range of 90 to 95 percent to about 70 percent.

When the digested sludge is deposited on a well-drained bed of sand, crushed anthracite coal, or similar coarse material, the entrained and dissolved gases tend to buoy and float the solids, leaving a layer of relatively clear liquor at the bottom which drains through the sand bed quite readily. The major portion of this liquid drains off in less than a day. After this brief period, evaporation becomes an important part of the dewatering process. As the liquid continues to percolate through the sand and evaporation continues, the sludge cake shrinks horizontally, producing cracks at the surface which accelerates evaporation by virtue of exposing new surfaces to the air. In climates where there is little rain and a high evaporation rate, sludge dries in a few days. Criteria for design vary with the type of treatment process producing the sludge and the area of the country. The range is 0.5 to 2.0 square feet per capita.

The beds usually consist of a bottom layer of gravel of uniform size about one foot deep over which is laid 6 to 9 inches of clean sand. Open-joint tile underdrains are laid in the gravel layer in a manner which provides positive drainage as the liquid passes through the sand and gravel. The beds may be open to the air or enclosed with glass or other light-transmitting materials in a structure similar to an ordinary greenhouse. The advantages of bed enclosures are that rain is kept off the beds, odors can be controlled, and they present a more pleasing appearance. Frequently, 25 percent less area is required when a bed is covered. Evaporation proceeds faster on open beds than covered beds during warm dry weather but much more slowly, during cold or wet weather. The use of covered drying beds is, however, not common in the Pacific Northwest.

(3) sludge lagoons. The considerable labor involved in sludge drying bed operation may be avoided by the use of sludge lagoons. These lagoons are nothing but excavated areas in which digested sludge is allowed to drain and dry over a period of months or even a year or more. They are usually dug out by bulldozers, or other dirt-moving equipment, with the excavated material used for building up the sides to confine the sludge. Depths may range from 2 to 6 feet. Areas vary, and although drainage is desirable, it is not usually provided.

Digested sludge is drawn as frequently as needed, with successive drawings on top of the previous ones until the lagoon is filled. A second lagoon may then be operated while the filled one is drying. After the sludge has dried enough to be moved, a bulldozer, or a tractor with an end-loader, may be used to scoop out the sludge. In some locations it may be pushed from the lagoon by dozers into low ground for fill.

Lagoons may be used for regular drying of sludge, re-used after emptying, or allowed to fill and dry, then leveled and developed into lawn. They can also be used as emergency storage when the sludge beds are full or when the digester must be emptied for repair. In the latter case the sludge should be treated with some odor control chemicals, such as hydrated or chlorinated lime.

The size of the lagoon depends upon the use to which it will be put. For example, a town of 5,000 could operate with two lagoons, say 25 feet by 100 feet (or 50 by 50 feet) each, and three feet deep, for a considerable time. This example is based on a capacity of three cubic feet per capita but more or less volume may be desired.

Lagoons may take the place of sludge beds or provide a place for emergency discharges of sludge, but they may be unsightly and even unwanted on a small plant site. However, they are popular because they are inexpensive to build and operate.

(4) digested sludge dewatering. Digested sludge may be dewatered by either vacuum filters or centrifuges. The processes are similar to those described previously for raw sludge.

(5) heat drying. Digested sludge may be heat-dried in special drying equipment similar to that previously described for the flash incineration process and then ground into a fine powder. This process is quite expensive and is seldom used in modern day treatment plants.

(6) incineration. Digested sludge may be burned in incineration units, in the same manner as previously described for raw sludge.

J. Digested Sludge Solids Disposal. Digested sludge may be disposed of on the surface of land areas either in liquid or dried cake form. Since the digested sludge solids are relatively biologically inert, it is not necessary to bury the solids and their distribution over the surface of land areas does not cause nuisance problems, although they may give rise to characteristic musty or stale odors for a few days following their application to the land surface. Dried digested sludge or dewatered digested sludge as produced by either vacuum filters or centrifuges, may be hauled by open-bodied trucks and disposed of either as land fill or spread in thin layers over the surface of the ground. The sludge has a relatively small and highly variable nitrogen content and as such does not make a particularly valuable fertilizer. It does serve, however, as a soil conditioning agent acting much like peat moss. Its use may be particularly valuable as a soil conditioner in areas having heavy clay-containing soils.

Liquid sludge withdrawn from digesters may be most easily handled in tank trucks equipped with large filling hoses and spreaders for discharge. Liquid sludge may be distributed from the truck or trailer-mounted tank to the ground surface as a liquid and either allowed to soak into the soil surface or disked or harrowed into the soil.

In any case digested sludge should not be applied to land areas where root crops for human consumption are being grown. It is also recommended that digested sludge not be spread over grasslands on which dairy cattle are pastured or over park areas or golf courses.

Many treatment plant operators faced with a problem in disposing of solids after treatment at their plants have devised ingenious schemes for advertising the value of the digested sludge to farmers and gardeners. Some treatment plant operators have been known to charge a small token fee for high quality dry digested sludge, and it is to be noted that this practice quite often results in the establishment of a regular clientele of local gardeners who often become very anxious to obtain supplies of digested sludge for their own usage. Basically, it may be stated that the theory behind this practice is that people generally are reluctant to take anything which is free for the asking because they believe it to have no value. If on the other hand, these same people can be convinced that they can buy something at a "bargain" price, they become very anxious to exercise their prowess as bargain hunters. By applying this same basic psychology on a much larger scale, many plant operators have been able to interest farmers in their area in the use of large amounts of either dried or liquid digested sludge as soil conditioner and "fertilizer". In most cases, no charge is made for the digested sludge material and plant operators may even go so far as to haul the dried or liquid sludge to the disposal area for the farmer and distribute it on the surface of the ground for the farmer.

Some city attorneys have been hesitant to recommend the disposition of digested sludge in this manner fearing the possibility of lawsuits rising from the disposition of sludge in this manner. Plant operators should discuss the matter of sludge disposal thoroughly with city officials prior to undertaking any program which may involve the public or private landowners.

K. Miscellaneous Other Methods of Sludge Disposal. In at least one instance, a large midwestern city faced with a difficult sludge disposal problem elected to dry their waste sludge, sterilize it, add supplements to the sludge and market it as a fertilizer. This material marketed under the trade name of "Milorganite" is sold all over the United States. The system which was improvised by the City of Milwaukee, Wisconsin provides that city with a relatively economical means of disposition of some of its sludge. This particular program has apparently generated sufficient income to the City of Milwaukee to justify its continuation. However, this instance remains today as the only commercial enterprise of its kind and the method has never proven profitable to other cities which have considered its use.

2. **Chemical Treatment.**

A. Flocculation. In very simple terms, flocculation may be defined as the bringing into contact and sticking together two or more small solid particles in order to form a single larger particle. From this simple definition, it may be seen that, in general, two distinct processes are required in order for flocculation to occur. These are, of course, the bringing together of particles and the sticking or adhering of one particle to another. With these two separate processes in mind, one can readily see that the flocculation process can be enhanced if some means of mechanical stirring or agitation is provided in order to create a situation wherein individual particles have a greater tendency to bump into each other. This is precisely the approach taken in the design of most flocculation equipment.

There are numerous ways in which the necessary agitation can be accomplished including mechanical paddle wheels rotating either horizontally or vertically, baffled mixing chambers in which flow is caused to reverse directions several times, and air diffusion devices which cause a rolling action within a chamber. Since the purpose of introducing mechanical energy loss into any flocculation system is to increase the number of contacts between individual particles, it may be inferred that the precise amount of energy required or agitation required would be a highly theoretical matter depending upon many variables including the number of particles in the waste flow to be flocculated, temperature, specific gravity of the particles and a host of other factors. It may also be inferred that since the purpose of agitation is to bring particles together that a very violent agitation process might tend to tear apart previously formed bits of floc. Both of these foregoing inferences are correct, and accordingly the required agitation is a sort of middle-of-the-road affair, having on the one hand a lower limit governed by the number of collisions between individual particles and an upper limit on the other hand, governed by the cleaving apart of previously formed floc.

The second required process in flocculation is the adhering together of individual particles after collision has occurred. In general most individual particles found in wastewater flows may be said to be surrounded by a small electrical charge. This electrical charge is generally negative in nature. Since like electrical charges tend to repel one another, it may be seen that two particles having the same charge tend to repel each other at any time that they are in contact together. Just as the earth and moon, for example, exert a gravitational pull on one another, so do any two solid particles exert a gravitational force on one another. This gravitational force increases rapidly as the distance between any two particles decreases. From the foregoing two statements it may be seen that on the one hand, while two like-charged particles tend to repel one another on contact, the particles themselves when brought into contact, have a gravitational attraction for each other. The interaction of these two forces is such, that in some cases the gravitational attraction is sufficient to keep the particles together even though the electrical forces might tend to try to separate the two particles. In other cases, solid particles may have such a strong electrical charge that the force thus generated will separate the particles because it is stronger than the gravitational attraction of one particle for another. In these cases, it may be advantageous to add materials which have the property to alter or rearrange the electrical charges in order to make flocculation more effective. Materials which have this ability are referred to variously as polymers, flocculant aids, and coagulant aids.

Since the field of flocculation is extremely technical in nature, its discussion for the purposes of this basic operator's manual has been purposely kept rather general in nature. In any event, it is usually necessary to perform extensive tests on any waste which shows a tendency to be difficult to flocculate in order to determine the best and most economical methods of flocculation.

For the purposes of waste treatment, the flocculation process is currently used for at least three specific purposes as follows:

(1) for improved settling. Flocculation and coagulation to improve efficiency of sedimentation basins has been practiced in many waste treatment plants since the early 1900's. In most cases the process has consisted of mixing coagulant aids with raw sewage, providing approximately 30 minutes detention time in a flocculation chamber and then passing the flocculated raw wastes into sedimentation basins. Common coagulant aids used in this process include alum, lime, and various iron salts. This process is not widely used in today's waste treatment plants because of the high cost of the various coagulant aid chemicals involved and because the sludge thus produced tends to be very bulky in nature and accumulates in great volume. Also the use of more efficient biological treatment systems following primary sedimentation has lessened the need for extremely high degrees of treatment for primary sedimentation units.

(2) for raw or digested sludge conditioning prior to dewatering. As previously described, sludge dewatering by means of either sludge filters or sludge centrifuges generally yields unsatisfactory results unless the sludge is preconditioned prior to dewatering. The preconditioning generally provided prior to dewatering is essentially a flocculation and coagulation process which is carried out in a very short period of time. Various coagulant aids have been found to be advantageous to this particular process. The most common coagulant aids used have been lime and ferric chloride; however, recently, the use of various manufactured polymers has become more and more successful.

(3) for phosphate removal. The commonly used primary and secondary sewage treatment processes do not appreciably reduce the amount of phosphate discharged in the effluent of most waste treatment plants. Since the discharge of phosphate containing effluent can have an extremely harmful effect on receiving waterways, it has become necessary in recent times to attempt to remove, in sewage and industrial waste treatment processes, as much phosphate as is possible. One method by which phosphates can be reduced is by flocculation and coagulation of the phosphate-containing wastes in the presence of either alum or lime. In the case of alum flocculation, floc particles which form absorb soluble phosphates and thus remove them from the wastes. In the case of the lime treatment, a chemical reaction takes place which converts the soluble phosphates into what might be broadly termed phospho-calcium compounds. In either case the soluble phosphate content of wastes thus treated may be remarkably reduced, and the amount of such reduction is at least generally proportional to the amount of alum or lime used in the treatment process.

B. pH Control. In any waste treatment plant in which either biological or certain types of chemical treatment are practiced, it is necessary that the pH of the incoming raw wastes be within certain broad limits in order for the necessary reactions to proceed properly. Accordingly, it is sometimes necessary to adjust the pH of raw incoming wastes in order to be certain that succeeding processes will proceed properly. A discussion of pH control measures for a few major reasons follows.

(1) for industrial effluents. Many industrial effluents can be either quite acid or basic in nature, and if allowed to pass on through biological secondary treatment processes or certain types of chemical treatment processes without adjustment, could be very detrimental to the processes. Broadly speaking, the microorganisms responsible for aerobic biological treatment such as activated sludge or trickling filter plants, operate at peak efficiencies in a pH range of from 7 to approximately 8.5. Above a pH of approximately 9.5, and below a pH of approximately 6.5, there is a marked decrease in biological efficiencies.

(2) for digesters. The anaerobic sludge digestion process is remarkably pH dependent and functions best at a pH of approximately pH 6.8 to 7.0. Anaerobic sludge digesters only rarely suffer from high pH problems. Usually pH control in anaerobic sludge digestion is necessary only to prevent acid conditions, that is, pH's much below 6.8. The anaerobic sludge digestion process will be more thoroughly discussed in a later section of this chapter; however, for the purposes of this particular section it may be said that the mechanism most adversely affected by low pH's in anaerobic sludge digestion is the activity of the methane-producing bacteria which are quite pH dependent.

(3) for proper biological environment. As previously discussed, all biological systems have an optimum pH range. In most cases, this pH range is from 6.8 to 8.5. It should be noted that many biological systems once well established tend to buffer themselves; that is, to resist changes in pH caused by slugs of high or low pH incoming waste. This fact is probably responsible for the continued normal operation of many plants that occasionally receive slugs of waste having an abnormal pH.

(4) for tertiary treatment and disinfection. Many tertiary treatment processes are definitely pH dependent not because of specific biological requirements but because of specific chemical reaction requirements. Since tertiary processes normally follow biological treatment processes, it may be necessary to drastically change pH's of biologically treated effluents in order to assure proper reactions through succeeding tertiary treatment processes which are more chemical and physical in nature than biological. Disinfection by chlorination is also somewhat pH dependent. Chlorination is more effective at slightly acid pH conditions (pH's below 7.0) than at alkaline pH's. The specific mechanism involved will be more thoroughly discussed in another chapter; however, for the purposes of this section it may be stated that current

theory holds that the hypochlorous acid formed by the action of chlorine and water is the most effective agent in disinfection and that more hypochlorous acid is formed under lower pH conditions than is formed at pH's above 7.0. Chlorination at pH's greater than 7.0 tends to promote the formation of certain ionized compounds which are not as effective in disinfection as is hypochlorous acid.

C. Disinfection and Chlorination.

(1) purposes of chlorination. Chlorine is added to sewage for a number of different purposes including disinfection, odor control and as an aid to various operating procedures. Each of these purposes is further discussed as follows:

a. disinfection. Neither primary nor secondary methods of sewage treatment remove completely from the sewage the pathogenic bacteria which are always potentially present. When sewage or treated effluents are discharged to bodies of water which are or may be used as a source of public water supply or for recreational purposes, treatment for the reduction of pathogenic organisms is required to minimize the health hazards of these effluents. Such treatment is known as disinfection. The term disinfection should not be confused with the term sterilization. Disinfection refers to the destruction of only pathogenic (organisms harmful to man or animals) organisms; whereas, the term sterilization refers to the complete destruction of all living organisms. Adequate disinfection requires that the pathogens in the effluent be destroyed. It is not necessary to sterilize the sewage since this would be extremely costly and completely impractical. To accomplish disinfection, sufficient chlorine must be added to satisfy the chlorine demand of the waste and leave a residual chlorine to destroy pathogenic bacteria. Disinfection must be a continuous process as it would be hazardous to discharge untreated effluent even for a short period of time. It is common practice to apply the chlorine at some point in the treatment plant after all secondary treatment has been accomplished but before the effluent is discharged to a receiving waterway. Since disinfection by the use of chlorine requires a considerable period of time, it is normal practice to provide either a chlorine contact chamber, or to actually apply the chlorine feed into final sedimentation basins if the plant is of the trickling filter type. Chlorine cannot be fed into final sedimentation basins serving activated sludge type treatment plants, since the application of chlorine at this point would adversely effect the operation of the aeration basins.

The process of applying a chlorine feed to treated effluents for purposes of disinfection is commonly known as post chlorination. In plants at which only primary treatment is provided, it is quite common practice to use the primary sedimentation tank as the chlorine contact chamber and apply the chlorine feed to the influent of this basin. This process is commonly called prechlorination. Since the primary object of chlorination is to disinfect the sewage and since a residual of chlorine is required for disinfection, it is necessary to apply much heavier dosages of chlorine in order to accomplish disinfection if prechlorination is practiced. The use of prechlorination does, however, have the advantage of minimizing odors which are sometimes present in primary sedimentation basins. Since the object of disinfection is the destruction of pathogenic bacteria, the ultimate measure of effectiveness of disinfection is the bacteriological result. It is impractical for most sewage treatment plant operators to perform bacteriological tests on their effluent. Accordingly, while this remains the only effective means of determining whether or not disinfection has been accomplished, some other means is needed to enable the plant operator to control the application of chlorine to the waste. The measurement of residual chlorine in sewage effluents provides such a tool. Procedures for determining residual chlorine in sewage or industrial waste effluents is described in a later section of this manual. In general, it is common practice to attempt to maintain a chlorine residual as determined by the previously mentioned test of 0.5 milligrams per liter after a contact time of at least 30 minutes. The State of Oregon now requires that chlorine contact be provided for a period of one hour after which the residual chlorine contact must measure at least 0.5 mg/l. The State of Washington is presently considering adoption of a similar requirement. Because of certain local conditions, this rule of thumb can only be general in nature and in some cases it may be necessary to maintain much higher residuals for extended periods of contact time in order to accomplish the necessary disinfection.

With normal domestic wastes the following dosages of chlorine should be sufficient to produce a chlorine residual adequate for disinfection:

TABLE 6-2

Type of Treatment Provided	Dosage (Based on Average Design Flow)	No./M.G.
Raw Sewage	20 – 25 mg/l	170 – 210
Primary Plant Effluent	18 mg/l	150
Trickling Filter Effluent	12 mg/l	100
Activated Sludge Effluent	6 mg/l	50
Sand Filter Effluent	6 mg/l	50

b. chlorination for odor control. The decomposition of sewage starts in sewers and becomes objectionable only after complete depletion of dissolved oxygen has occurred. The degree of decomposition which occurs is related to the time that sewage is held in the sewer system as well as the temperature of the wastes. Odor problems, therefore, generally only develop where sewers are long or where it is necessary to collect sewage in wet wells and subsequently pump the sewage to a treatment plant. If conditions arise which cause release of odors in long sewer systems, it may be possible to chlorinate the sewage at a manhole or pump station wet well in order to help control the odors. The amount of chlorine required varies depending upon how long the decomposition of sewage must be delayed. It is not necessary to add sufficient chlorine to satisfy entirely the chlorine demand of the waste. The addition of only sufficient chlorine to destroy the odors and to retard bacterial decomposition is usually sufficient. Dosages of from 4 to 6 milligrams per liter are generally found to be sufficient to control odors. When attempting to determine proper dosages for control of odors, it is normal practice to start with fairly high dosages of chlorine such as 10 milligrams per liter and to gradually reduce the dose over a period of time to determine the minimum dosage which will satisfy local conditions.

c. chlorination as an aid to plant operation. Prechlorination at the influent of a sedimentation tank is sometimes used in order to control odors which arise from the effects of stale sewage being discharged into such sedimentation basins. As previously mentioned, this type of prechlorination generally will result in enhanced settleability of sewage solids. However, the added efficiency thus gained is seldom justified by the cost of prechlorination. Accordingly, if prechlorination is practiced it is generally done for purposes of odor control rather than for improved settling characteristics.

Offensive odors released during the distribution of sewage over a trickling filter can generally be controlled by applying chlorine at the primary tank effluent. The dose used is not sufficient to produce residual chlorine but only to destroy the odors. If the dosage rate is too high, serious damage to the biological film on the filter media may result. This in turn may lead to reduction in filter efficiency.

As will be discussed in a later section, the application of massive doses of chlorine to trickling filters is sometimes used in order to promote the rapid killing and removal of slimes which occasionally occur on trickling filters. This practice requires a fairly large dose of chlorine to produce the necessary results. As it is only used as an emergency remedy to unplug filters, it is generally best to chlorinate filters during night times when the flows to the treatment plant are low and the chlorine demand is at a minimum.

When ponding on trickling filters is caused by an excessive growth of filamentous organisms, continuous chlorination of the filter influent may be used for control. As will be more thoroughly discussed in a later section, if the ponding is caused by simple overloading of the filter, chlorination although it may affect some temporary results is not a cure for the problem. It is customary to apply chlorine to a ponding filter by chlorinating the filter influent to produce a residual of about 2 milligrams per liter at the distribution nozzles.

(2) chemistry of chlorine in water. The destruction of bacteria and other microorganisms by a substance such as chlorine is essentially the result of the chemical reaction between the active

agent and some vital substance necessary to the functioning of the organism. When chlorine is dissolved in water it undergoes a reaction termed hydrolysis which results in the formation of hypochlorous acid plus a number of other chemical ions. In concentrations of up to 3,000 milligrams per liter at approximately neutral pH's, the hydrolysis reaction is virtually complete and occurs extremely rapidly so that only a few seconds are required in order to complete the reaction. The hypochlorous acid thus formed, itself then ionizes or dissociates into hydrogen and hypochlorite ions. The dissociation of the hypochlorous acid is extremely pH dependent. Below pH's of approximately 3.0, no dissociation occurs; and above pH's of about 8.0, complete dissociation occurs. Unfortunately, it is the hypochlorous acid which is the effective agent in disinfection. Because of the tendency of the hypochlorous acid to dissociate at the normal pH's encountered in sewage treatment processes, it is necessary to apply heavier dosages of chlorine than would be required if very low pH's were present. Figure 6-19 graphically illustrates the relationship of pH to free and combined forms of chlorine. As may be seen from this figure, there is a tendency for the hypochlorous acid to convert itself into what is known as the hypochlorite ion as pH's increase. Table 6-3 expresses the percentage of free chlorine present as hypochlorous acid, and the total free chlorine dose required to obtain a hypochlorous acid residual of one part per million at various pH's.

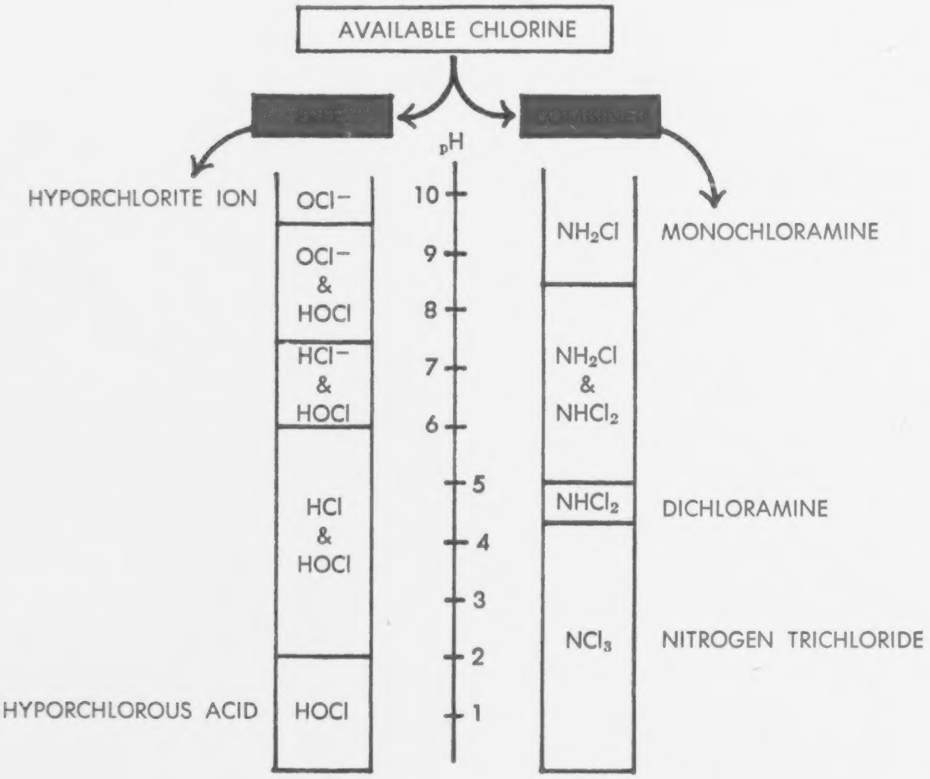
AVAILABLE CHLORINE
pH
HYPORCHLORITE ION
OCl−
OCl− & HOCl
HCl− & HOCl
HCl & HOCl
HYPORCHLOROUS ACID
HOCl
10
9
8
7
6
5
4
3
2
1
NH₂Cl
MONOCHLORAMINE
NH₂Cl & NHCl₂
NHCl₂
DICHLORAMINE
NCl₃
NITROGEN TRICHLORIDE

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Figure (6-19)
RELATIONSHIP OF pH TO FREE
AND COMBINED CHLORINE

TABLE 6-3

pH HYPOCHLOROUS ACID RELATIONSHIP

pH	Hypochlorous Acid Percent	Free Cl Dosage Req'd. to Obtain a 1 mg/l Hypochlorous Acid Concentration
4	100	1.000
5	99.7	1.003
6	96.8	1.033
7	75.2	1.33
8	23.3	4.3
9	2.9	34
10	0.30	331
11	0.030	3,300

The reactions of chlorine with ammonia contained in most sewage and industrial wastes are of great significance in the chlorination of wastes particularly for disinfection purposes. When chlorine is added to water containing ammonia, a combined chlorine residual (which contains very little if any hypochlorous acid) is formed. The chemical combination of chlorine and ammonia is usually referred to as chloramines. The chloramines which are thus formed are much less effective as disinfectants than is free residual chlorine (hypochlorous acid). The difference between disinfecting abilities of the free chlorine and combined chlorine is such that approximately 100 times as long is required to effect disinfection with combined chlorine as is required with free chlorine. Unfortunately, ammonia is nearly always present in domestic sewage; and accordingly, contact periods on the order of 30 minutes to one hour are almost always necessary in order to effect disinfection, since with the chlorine dosages normally employed at sewage treatment plants, very little or no free chlorine will be available; and the entire job must be done by the combined chlorine residual (chloramines). The pH of the waste being chlorinated also has a pronounced effect upon the disinfecting properties of chloramines. However, in the case of chloramines, the lower the pH, the more effective are chloramines as disinfectants. Temperature also has a pronounced effect upon the disinfecting properties of either free chlorine or chloramines. In this case the effect is the same for both free and combined chlorine residuals. Generally, the lower the temperature, the less effective is the disinfection process.

D. Removal of Chemical Nutrients, Toxicants and Other Organic or Inorganic Chemicals. Chemical and physical treatment processes are beginning to play an ever-increasing role in the removal of such things as nitrogen compounds, phosphorous-containing compounds and various carbon-containing compounds, concentrations of which have not been materially decreased by present day biological secondary treatment processes.

(1) purpose. As is well known to most treatment plant operators, conventional secondary biological treatment processes do not remove most of the nitrogen and phosphorus and many "exotic" chemicals present in waste flows. These substances, in passing through our present day conventional treatment processes, have often times proven to be extremely detrimental to receiving waterways. Increased effort is being directed toward their removal in order to protect the streams. Examples might include detergent removal and nitrogen removal.

Detergents used to present a major problem in many treatment plants because of their tendency to foam and the inability of biological processes to attack the specific chemical substance in detergents and to alter its structure to reduce foaming problems. Because of this particular problem, the detergent industry as a whole spent considerable time and money investigating new formulations for detergents and recently have been successful in producing a different type of detergent which retains the desirable detergent properties but which is biologically degradable. Because of this concerted effort on the part of both regulatory agencies and detergent manufacturers, present conventional biological secondary treatment plants now are able to remove a large portion of detergents from the waste flow thus reducing the ultimate phosphate load on receiving waterways. Another problem familiar to most treatment plant operators is the often massive growth of algae in waters receiving treated effluent. Often times this algae growth is triggered by the excess of nitrogen present in various forms in treated effluent. Most conventional biological secondary treatment plants do not appreciably reduce the total amount of nitrogen present in incoming raw wastes but rather change it in form from ammonia to nitrates. The nitrates which pass out with the effluent thus form a large reservoir of nitrogen which tends to spur the growth of algae. In this respect it should also be pointed out that another essential item for the growth of algae is phosphorus. Even with the use of improved detergents, enough phosphorus generally remains in the treated effluent to make it possible for algal growth to utilize nearly all of the nitrogen passed in the effluent. These two examples tend to illustrate the need for more complete types of treatment in order to reduce nitrogen and phosphorus concentrations as well as concentrations of "exotic" chemicals in order to protect receiving waterways.

(2) methods. Present day technology has developed several methods which make it possible to eliminate or at least drastically reduce the amount of chemical nutrients contained in treated effluents. While a complete description of many of these methods is beyond the scope of this basic manual, operators should at least be aware that methods are available for the removal of these substances. Some of the methods currently in use or under active investigation are as follows: coagulation, sedimentation, filtration, adsorption on granular activated carbon, deionization, chemical stabilization, and stripping. Figure 6-20 graphically illustrates these methods and indicates how several of the methods have been combined in at least one presently operating tertiary treatment plant.

(3) equipment used. Equipment used in tertiary treatment processes does not in most cases differ appreciably from equipment which has been used in conventional waste treatment plants or water treatment plants. For example flash mix and coagulation equipment often used in tertiary treatment is similar to equipment used in many present day water treatment plants.

Sedimentation basins are in most cases similar to those presently used in conventional waste treatment plants. Filtration equipment can be either of the pressure or gravity type in which effluents are passed through fine media in order to physically filter or strain particulate matter from the flow. Some tertiary plants are today using gravity sand filters which are not appreciably different than those initially developed over 100 years ago.

Carbon absorption and deionization equipment generally takes the form of packed columns and is similar to equipment used in many present day industrial water treatment plants where extremely high grade water is required for various manufacturing processes. Stripping towers currently in use in tertiary treatment are very similar to cooling towers which have been used for years in industrial application such as power plants.

(4) testing and control of processes. As more and more individual unit processes are added to treatment plants in order to accomplish tertiary treatment, more and more laboratory testing is required in order to control these processes. In addition to the tests normally performed, such as the BOD, suspended solids, dissolved oxygen and others, it is necessary to add specific tests for specific chemical constituents in order to assure the proper operation of tertiary plants. A few of the added tests might be complete nitrogen analysis including ammonia nitrate and nitrite analyses, phosphate tests, pH testing at various points in the process flow, tests for calcium in the event that lime is used as the coagulant, tests for activity of carbon in the case of carbon filtration, and tests for specific ions in cases where treatment is followed by passage through deionization columns.

3. **Biological and Biochemical Treatment.**

A. Biological Filters (trickling filters).

(1) purpose. The purpose of trickling filters is to remove nonsettleable suspended matter and colloidal and dissolved organic matter from settled sewage. This is accomplished by biological slime growth on the filter media through aerobic biodegradation and conversion of the nonsettleable suspended matter and colloidal and dissolved organic matter to liquids and gases and settleable solids which are removed in the final settling basins. Trickling filters are not primarily a filtering or straining process as the name seems to imply but are instead a technique for promoting contact between the liquid waste and an active growth of biological organisms.

(2) theory. A trickling filter is a bed of relatively large sized rock or crushed stone, or in some cases plastic media or redwood slats arranged

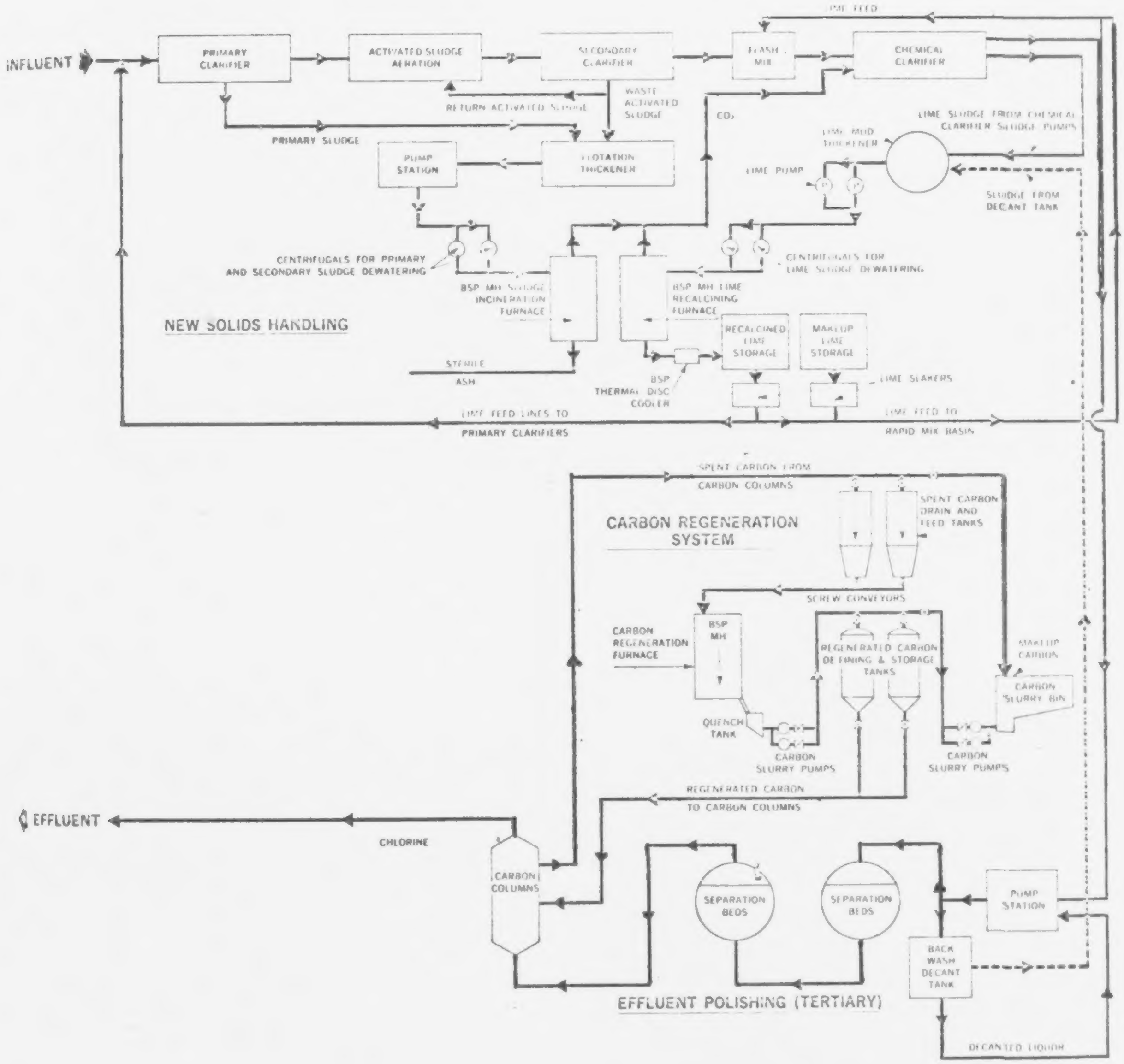
INFLUENT
PRIMARY CLARIFIER
ACTIVATED SLUDGE AERATION
SECONDARY CLARIFIER
FLASH MIX
CHEMICAL CLARIFIER
LIME FEED
RETURN ACTIVATED SLUDGE
WASTE ACTIVATED SLUDGE
CO_2
PRIMARY SLUDGE
PUMP STATION
FLOTATION THICKENER
LIME SLUDGE FROM CHEMICAL CLARIFIER SLUDGE PUMPS
LIME MUD THICKENER
LIME PUMP
SLUDGE FROM DECANT TANK
CENTRIFUGALS FOR PRIMARY AND SECONDARY SLUDGE DEWATERING
CENTRIFUGALS FOR LIME SLUDGE DEWATERING
BSP MH SLUDGE INCINERATION FURNACE
BSP MH LIME RECALCINING FURNACE
NEW SOLIDS HANDLING
RECALCINED LIME STORAGE
MAKEUP LIME STORAGE
STERILE ASH
BSP THERMAL DISC COOLER
LIME SLAKERS
LIME FEED LINES TO PRIMARY CLARIFIERS
LIME FEED TO RAPID MIX BASIN
SPENT CARBON FROM CARBON COLUMNS
CARBON REGENERATION SYSTEM
SPENT CARBON DRAIN AND FEED TANKS
SCREW CONVEYORS
CARBON REGENERATION FURNACE
BSP MH
REGENERATED CARBON DEFINING & STORAGE TANKS
MAKEUP CARBON
CARBON SLURRY BIN
QUENCH TANK
CARBON SLURRY PUMPS
CARBON SLURRY PUMPS
REGENERATED CARBON TO CARBON COLUMNS
EFFLUENT
CHLORINE
CARBON COLUMNS
SEPARATION BEDS
SEPARATION BEDS
PUMP STATION
BACK WASH DECANT TANK
EFFLUENT POLISHING (TERTIARY)
DECANTED LIQUOR

Figure (6-20)
TYPICAL UNIT PROCESSES
IN TERTIARY TREATMENT

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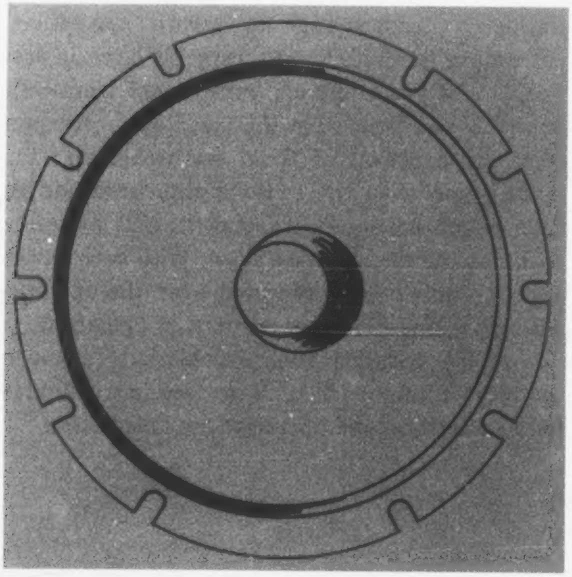
to provide as great a surface area as possible within the smallest volume. Settled waste is applied over this bed of media in such a way that it trickles uniformly down through the bed thus exposing all surface areas of the media to the settled waste flow. The trickling filter media provides a surface upon which millions of microorganisms such as bacteria, protozoa, fungi and algae may attach themselves to form what is commonly called a zoogleal film.

These organisms require at least two essentials for life, food and dissolved oxygen. Food is supplied in the form of the organic waste which is distributed on the surface of the filter and allowed to filter through the void spaces passing over the zoogleal film on the rock. Oxygen is supplied in the form of air which may pass either upward or downward through the filter depending upon the difference in temperature of the waste and the surrounding air.

Underlying and supporting the media on which the zoogleal film grows, is an underdrain system which serves three main purposes. It supports the weight of the media above the underdrain system; it provides a system of small individual channels which collect the flow of waste trickling down through the media and delivers it to a central channel; and finally it provides an open area above the depth of collected waste which is available for the free passage of air which in turn is distributed through the entire volume of filter media.



WEMCO PUMP SUCTION PLATE
Figure (6-21)

As the settled waste passes over the biological organisms contained in the film, a part of the organic matter is used for energy by the organisms. This part of the organic matter, is converted to carbon dioxide, water, and mineral solids. In this process the organisms convert part of the organic matter to ammonia, nitrite, nitrate, and sulfates, the end products of decomposition. Most of the remaining organic matter is caught in the slime and stored for future use or is used in the growth of new organisms in the process of building new cell material for the zoogleal film. This continuous build-up of the zoogleal film tends to increase the thickness of the slime on the filter media. Some of the slime continuously falls away from the filter media and is carried by the waste flow through the underdrain system to a final settling basin. This continual loss of biological slime from the filter media is commonly termed sloughing. Since the organisms which are continuously being removed from the filter media represent a sizeable portion of the BOD applied originally to the filter, it is necessary to remove these organisms from the treated waste flow if an efficient process is to be established. It is for this reason that final settling basins are normally used following treatment by trickling filters. The purpose of the final settling basin is, of course, to settle these organisms which have sloughed from the filter thus removing them from the final effluent flow. In most cases the sludge thus produced in the final settling basin is returned to the primary settling basin where it is again settled and collected with raw sludge to be removed for further treatment.

(3) pretreatment. Pretreatment of the waste to be applied to a trickling filter is essential for good filter operation. Ineffective primary treatment of sewage will increase the amount of suspended solids reaching the filter and may cause plugging and overloading of trickling filters. Normal practice is to provide primary sedimentation facilities to remove about 30 percent of the organic matter (BOD) ahead of treatment by trickling filters.

(4) classification of filters. Trickling filters are classified according to the applied hydraulic and organic loadings. The hydraulic loading is the total volume of sewage including recirculation per day (applied to a trickling filter) per square unit of the filter area. The general practice has been to express the hydraulic loading in terms of millions of gallons per day per acre (mgad) or in gal-

lons per day per square foot. The organic loading is the pounds of BOD applied per day per unit volume of filter media. The units used to express this are generally pounds of BOD per 1,000 cubic feet per day (ptcfd).

Trickling filters are grouped into two classifications, standard or low rate filters and high rate filters. For the purposes of classification, the following ranges have been adopted by the Water Pollution Control Federation.

TABLE 6-4

CLASSIFICATION OF TRICKLING FILTERS

	Low Rate Filters	High Rate Filters
Hydraulic Loading		
gallons/day/square foot	25-100	200-1,000
million gallons/acre/day	1.1-4.4	8.7-44
Organic Loading		
pounds/1,000 cubic feet/day	5-25	25-300
pounds/acre foot/day	220-1,100	1,100-13,000

In a standard rate trickling filter the biological oxidation is accomplished in one pass of the sewage through the filter; whereas, with the higher loadings on the high rate trickling filter, it is usually necessary to recirculate the filter effluent to the incoming waste for at least one and perhaps several additional passes through the trickling filter.

The principle asset of a high rate filter is that the equalization of loading by recirculation provides a greater removal of organic material per unit volume of filter media than is removed in the standard filter. As an example, compare a standard filter loaded at the rate of 400 pounds of BOD per acre foot per day against a high rate filter loaded at 3,000 pounds of BOD per acre foot per day. The standard filter will remove about 80 percent or 320 pounds per acre foot of the applied BOD while the high rate filter will remove about 65 percent or 1,950 pounds BOD per acre foot per day. Thus with the same volume of media in the two types of filters, the high rate filter will remove about 6 times as much BOD, but it will also leave approximately 13 times more organic material in the filter effluent.

Slugs of industrial waste or shock loads are diluted in the recirculation process and the effect of these wastes is spread out over a longer period of time, thereby reducing shock effects. A more uniform distribution of waste over the bed is another advantage frequently provided by recirculation in high rate filters.

Trickling filters can be installed to operate in series or stage operation. There are a number of combinations used, but one of the more common is to install a high rate filter as a "roughing" filter followed by a standard rate filter. The objective is to take advantage of the high BOD reduction per unit volume of rock which can be obtained in the high rate operation and then pass the waste through a standard filter to "polish" the effluent i.e., reduce the BOD to an acceptable level. In practice, if the two units are constructed identically, one filter can be used as the first stage or roughing filter for a period of time, say two weeks to a month, and then the series is alternated and the filter which previously acted as the first stage filter becomes the second stage filter. With such design, any one unit can be removed from the operation without taking any other unit out of operation.

(5) trickling filter calculations. Some of the more common calculations used in trickling filter classification and operation are as follows:

$$\text{Hydraulic Loading} = \frac{\text{Million Gallons}}{\text{Day}} \times \frac{1}{\text{Area (Acres)}} = \text{Million Gal./Acre/Day}$$

$$\text{Organic Loading (BOD)} = \frac{\text{Million Gallons}}{\text{Day}} \times \frac{8.33\text{ lbs.}}{\text{Gallon}} \times \frac{\text{BOD in Parts}}{\text{Million}} \times \frac{1}{\text{Filter Vol. in Thousand Cu. Ft.}}$$

OR

$$= \frac{\text{lbs. BOD}}{\text{Day}} \times \frac{1}{\text{Filter Vol. in Thousand Cu. Ft.}} = \text{Lbs. BOD/Thousand Cu. Ft. per day}$$

$$\text{Recirculation Ratio (R) } R = \frac{\text{Recirculated Flow}}{\text{Sewage Flow}}$$

$$\text{Recirculation Factor (F) } F = \frac{1 + R}{(1 + o.1R)^2}$$

$$\text{Effective BOD Loading} = \frac{W}{V \times F}$$

where W = Organic Loading in Lbs. BOD
V = Filter Vol. in Acre Feet
F = Recirculation Factor

The approximate efficiency of well-operated filters and settling basins following them can be calculated from many different formulas. Perhaps the most widely used formula for calculation of expected trickling filter efficiency is one which has been developed by the National Research Council (NRC). This formula is as follows:

For standard rate and single stage filters –

$$\text{Efficiency (Percent)} = \frac{100}{1 + 0.0085 \times \frac{W}{VF}}$$

For the efficiency of a second stage filter in a two stage trickling filter system –

$$\text{Efficiency (Percent)} = \frac{100}{1 + \frac{0.0085}{1 - E_1} \times \sqrt{\frac{W_2}{VF}}}$$

where E_1 = percent efficiency in the first stage filter

W_2 = lbs. BOD remaining in settled first stage filter effluent

(6) equipment. There are only 3 major types of equipment used in conventional types of trickling filters. The 3 types of equipment which have been used can be classified into fixed nozzle distributors, traveling type distributors and rotary reaction type distributors. The fixed nozzle and traveling type distributors are not often used today but were widely used in plants designed 30 or 40 years ago.

Fixed nozzle distributors simply consisted of a network of nozzles fixed in place, over the media, by which the waste flow was distributed. The fixed nozzles each were expected to uniformly distribute waste flow over a certain area of the trickling filter and often had rather small openings in order to help distribute the entire waste flow to all the fixed nozzles. These small openings, of course, have a serious disadvantage in that they plug easily and are difficult to clean. Because of rather poor overall waste distribution obtained by the use of fixed nozzles, this type of distribution is not commonly used today.

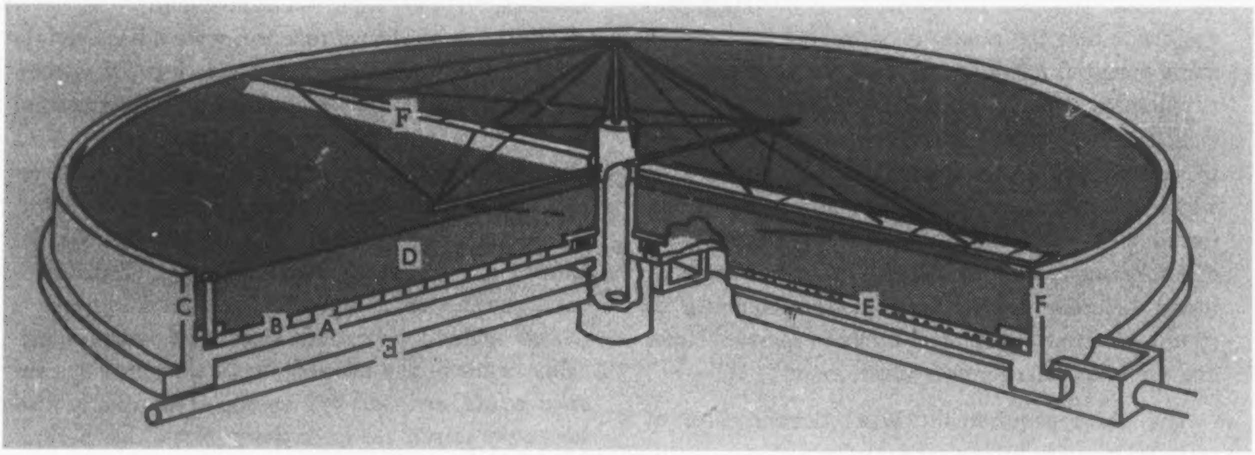
The traveling distributor generally consists of a metal trough equipped with splash plates which span the entire width of a rectangular trickling filter. This trough is caused to traverse back and forth across the surface of the trickling filter generally riding on rails provided in the sidewalls of the filter. The traveling distributor is in some cases driven by an electrical motor with power supplied by an aerial cableway system or in other cases was powered by a turbine motor driven by the flow of waste to the distributor. This particular type of distributor overcame the problems associated with plugging, but since it had to traverse from one end of the filter to the other before returning to its starting point, it suffered from the disadvantage of allowing the filter media to dry out rather severely between successive passes of the distributor. Because of this reason, the traveling distributor has never found wide usage in trickling filters.

The most common type of trickling filter distributor is the rotary reaction type which in essence operates like a large rotary lawn sprinkler. This type of distributor consists of two or more arms which rotate about a central center column and which are equipped with orifices and splash plates. Flow exiting from opposite arms is directed in opposite directions and the reaction force thus created by the waste flow in leaving the orifices, pushes the arms around. In some cases, rotary distributors are designed in such a way that during periods of low waste volume, only two of the four arms are used and during periods of high waste flows all four arms are used. This feature helps to assure even distribution of flows.

Because the waste flow enters any rotary distributor from a fixed pipe while the distributor itself is rotating, it is necessary to provide some sort of seal between the rotating and fixed elements of the distributor. Two types of seals are in common usage today, both of which have proven to be quite satisfactory. One type of seal employs the use of a reservoir filled with mercury in which an upper baffle or seal plate rotates. Since mercury has a weight of nearly 14 times that of water, it may be seen that a slight depth of mercury acting as a seal can withstand the pressure generated by a depth of water equal to almost 14 times that of the mercury. Usually the only problems associated with this type of seal are the necessary periodic cleaning of the mercury and occasional replacement in the event that the seal is inadvertently blown out by too high pressures. Most distributors equipped with a mercury seal are provided with a trap which catches the mercury in the event that the seal is blown.

The other type of seal commonly used in rotary distributors is called the mechanical seal. This type of seal is either usually grease or oil lubricated and simply consists of a stationary lower plate and a revolving upper plate with either grease or oil lubrication provided between the stationary and moving parts of the seal. This type of mechanical seal has proven to be fairly maintenance free; however, wearing surfaces do require some maintenance and periodic lubrication is required. Figure 6-22 shows a typical schematic view of a circular trickling filter equipped with a rotary reaction type distributor.

(7) expected treatment efficiencies. Trickling filter plants as commonly used today for providing secondary biological sewage treatment normally may be expected to provide between 80 and 85 percent overall reduction of BOD through the entire plant. In some special cases trickling filter plants have been shown capable of providing as high as 95 percent overall treatment efficiency; however, efficiencies of this magnitude are the exception rather than the rule.



A–Filter Bottom
B–Underdrain Blocks
C–Filter Walls
D–Filter Media
E–Filter Influent Column
F–Rotary Distributor

Figure (6-22)
TYPICAL TRICKLING FILTER

B. Activated Sludge Systems.

(1) purpose. The purpose of activated sludge treatment systems is to remove either settleable or nonsettleable suspended or colloidal solid and dissolved organic matter from waste. This removal is accomplished by introduction of the waste to be treated into a biological system containing a high concentration of actively growing organisms in the presence of dissolved oxygen. The biological organisms utilize the waste material as a source of food so as to obtain the energy necessary for their own life processes and in so doing convert the waste materials into more stable end products. The rapid growth of the organisms responsible for treatment results in the creation of a flocculant biological mass which can be removed by sedimentation thus creating a relatively clear, stable effluent. Early researchers, having discovered the beneficial effects of subjecting raw wastes to a large concentration of this biological mass in the presence of oxygen, believed that the biological mass was in some way activated by its exposure to oxygen and sewage; hence, the term activated sludge was coined and is today applied to any biological system operating in the manner above described. Actually, the biological systems responsible for treatment are not really activated or changed in any manner by their exposure to waste and oxygen. The organisms grow in the same manner which they would normally, except that in the activated sludge process the concentration of active biological mass is kept very high by continuously recycling of organisms back into the aeration system. In this manner the active organisms are used over and over again.

(2) theory. In simplest terms the activated sludge system may be described as a biological reactor in which waste to be treated and the high concentration of active biological organisms are placed into intimate contact under conditions of a high degree of mixing and adequate dissolved oxygen. Assuming that the waste to be treated contains all of the essential nutrients necessary to the life processes of the active biological organisms, it can be seen that this set of conditions will produce an environment in which the biological system will be able to expand in a fashion limited only by its own inherent growth rates and the concentration of essential nutrients available. Since the inherent growth rates of most of the organisms involved in waste treatment are extremely rapid, it can be seen that if the concentration of active organisms is maintained at a high enough level, extremely high degrees of treatment are possible in relatively short periods of time.

Referring back to our definition of an activated sludge system, we see that in simplest terms only five items are necessary in order to establish an activated sludge treatment process. First, we must have a source of food to support the life processes of the biological organisms. This source of food is, of course, supplied by the waste to be treated. In the event that the waste to be treated is lacking in some essential nutrients, it is of course possible to supplement these as required.

Secondly, a basin or reactor is needed in order to contain the entire system. This is the tank in which the treatment takes place and is usually referred to as the aeration basin. The aeration basin can take many shapes and can be constructed in many different ways. Examples are rectangular or round concrete tanks, steel tanks in various shapes and even earthen or gunite-lined ponds.

The third requirement is a concentration of actively growing biological organisms. These organisms are usually referred to as active mass and can be obtained either from other activated sludge plants presently in operation or by developing it on-site in a new treatment plant. Since small concentrations of all of the organisms chiefly responsible for the action of activated sludge plants may already be found in almost any waste containing an appreciable amount of domestic sewage, higher concentrations may be developed by aerating the wastes and returning back to the aeration chamber, all sludge which settles from the effluent of the aeration chamber. Over a period of time, if this process is continued long enough, an active mass can be created.

The fourth and fifth items required are a source of dissolved oxygen and adequate mixing. In most cases, the same equipment used to supply the dissolved oxygen also provides adequate mixing. There are a number of methods of supplying the dissolved oxygen. The two most common methods are the introduction of compressed air through underwater air outlets and the use of mechanical aeration equipment. The use of compressed air is generally termed bubble aeration because the air is released under the surface of the liquid in the form of either small or large bubbles which rise rapidly to the surface of the aeration basin thus causing high velocities and mixing as well as imparting dissolved oxygen into the waste flow. The use of aeration machines is normally termed mechanical aeration. There are many types of mechanical aerators; however, in principle they all subject the liquid in the aeration basin to a vigorous mixing action by means of submerged propeller blades or rotating horizontal brushes. This causes a tremendous mixing and splashing within the contents of the aeration basin thus providing adequate mixing and introducing oxygen from the atmosphere.

Once the biological reaction system has been established within an aeration basin, it is only necessary to continue introducing food into the system in the form of wastes to be treated; oxygen into the system by means of aeration equipment; removal of the active biological mass from the system by means of a final sedimentation; and recirculation of the sludge obtained from the final sedimentation basin back into the biological reactor. Such a closed cycle of operations would, of course, inevitably result in the overloading of the entire system with solids and for this reason it is usually also necessary to remove from the system either periodically or on a continuous basis a small amount of solids created in the system. The solids thus removed from the cycle are usually termed waste sludge and these solids are normally handled in the same manner as other sludges, that is, removed for further treatment either by digestion or other means.

Because of the tremendous number of variables involved, the operation of any activated sludge treatment system is not as simple as might be expected from the foregoing discussion. In order to fully understand the theory behind the system it is necessary to consider what actually occurs in the life processes of the biological organisms responsible for treatment at various stages in the treatment process. As will be discussed more thoroughly in Chapter VII of this manual, the organisms responsible for treatment in an activated sludge system may either be in an active growth phase or in a phase in which new growth is absent but in which the organisms continue to live by utilizing their own cells as a source of food. In between these two extreme growth phases are intermediate phases having some of the characteristics of both of aforementioned phases. For the purposes of this manual it may be convenient to refer to the phase in which rapid growth occurs as the active growth phase and the phase in which no new growth occurs as the endogenous phase. This terminology is widely used in sanitary engineering. It is probably wise to utilize these rather technical terms in our discussion even though the use of simpler language would otherwise be preferable.

When any biological system is subjected to a large excess of essential nutrients (food), proper environment including pH conditions and temperature, and an excess of dissolved oxygen, the only thing which limits the rate at which the biological system can grow is the speed with which the various organisms can reproduce. Under such conditions, any biological system is able to multiply very rapidly and is referred to as being in the active growth phase. Under these circumstances wherein nothing is limiting excepting the reproduction rate, the biological organisms exhibit certain characteristics which include a very high energy level of the individual organisms. Under these conditions, the organisms do not tend to flocculate nor will they settle primarily because they have sufficient energy in order to move or swim freely about in the liquid system.

If on the other hand, a biological system is subjected to a condition wherein there is insufficient food available to allow growth to occur as fast as the reproductive rate would allow, the system is said to be limited by the food available and because of this limiting factor, growth progressively slows down until at last food becomes practically nonexistent. Under these conditions the biological organisms characteristically have a very low energy level and in order to survive begin actually to consume portions of their own cell structure as a source of food. Under these circumstances the organisms exhibit a tendency to clump together or flocculate and settle rather easily.

Since the success of any activated sludge system depends to a large extent on the ease with which biological organisms can be separated from the liquid phase of the system in a final sedimentation basin, it may be apparent that unless activated sludge systems can be operated in the endogenous growth phase it is not possible to create a stable, well-operating, activated sludge system. Recalling that the endogenous growth phase can be created under circumstances where food is limiting, it is apparent that there are at least two methods by which endogenous growth can be encouraged. One method is to keep the concentration of biological organisms so high that the incoming waste flow does not supply sufficient food for active growth. The other method is to provide such a long contact time in the aeration basin that, before exiting from the aeration basin, the biological organisms consume the available food and reach an endogenous growth phase. Actually these two criteria are always combined in any activated sludge system in order to provide proper operation.

(3) pretreatment. Activated sludge systems, being for the most part entirely carried out in basins containing only liquid, do not require for their proper operation, extensive pretreatment. About the only pretreatment normally required is grit removal and grinding of large solids. Since the amount of oxygen which must be supplied to any activated sludge system is a function of the BOD loading applied, it can be seen that any pretreatment which is applied ahead of activated sludge system in order to reduce the BOD loading applied would reduce the amount of oxygen which must be supplied to the system. The oxygen which must be supplied requires the expenditure of energy, and this energy costs money. Because of this fact, it is conventional practice to provide primary sedimentation ahead of most activated sludge plants. This primary sedimentation process normally will remove up to 30 percent of the applied BOD load, thus reducing oxygen and energy costs accordingly. The question of whether or not to provide primary sedimentation ahead of activated sludge treatment is purely one of economics. That is, if it is less expensive to remove a portion of the BOD loading by means of primary sedimentation, than to treat the entire flow without primary sedimentation, then primary sedimentation is usually provided. In some cases such as might occur in wastes in which the BOD is almost all dissolved, primary sedimentation ahead of activated sludge processes is of little value and is not used. A typical example of the waste having a high concentration of soluble BOD might be the waste from a creamery operation. Certain types of food processing and drug manufacturing wastes also fall into this category and in these cases it is not normally economical to precede activated sludge processes with primary sedimentation unless considerable amounts of domestic wastes are also present.

(4) classification of activated sludge processes. The activated sludge process in general has been one of the most highly researched and investigated treatment systems in use today. Consequently, there has evolved a tremendous number of various modifications of the process, each of which may be slightly different than any other type used. It is beyond the scope of this basic Operator's Manual to discuss all of these many modifications; however, a few of the more common processes normally used will be briefly discussed. Activated sludge processes may be classified in two separate ways as follows: classifications based on loading factors, and classifications based on other factors. The usual means of classifying activated sludge

processes by load is illustrated in Table 6-5 which follows:

TABLE 6-5

CLASSIFICATION OF ACTIVATED SLUDGE PROCESSES BY LOAD

Process Name	Usual Loadings
High rate activated sludge processes	BOD loadings greater than 0.3 lbs. BOD per lb. of solids under aeration
Standard rate activated sludge processes	BOD loads from 0.1 to 0.3 lbs. per lb. of solids under aeration
Low rate activated sludge processes	BOD loads less than 0.1 lbs. BOD per lb. of solids under aeration

Activated sludge processes may also be classified according to other basic parameters. A few of the major processes currently in use are as follows:

a. plug flow. The plug flow activated sludge process was the first process to be used on a continuous flow basis. The process derives its name from the fact that the aeration basins normally used are rather long and narrow, having a length at least 5 times greater than the width and because all of the untreated waste flow is introduced at one end and taken from the aeration basin at the other end. In general, plug flow systems are equipped with diffused air aeration devices arranged lengthwise along the tank and at one side in such a manner that the air bubbles thus released tended to give the entire contents of the aeration basin a circular rolling motion which revolves on an axis parallel to the length of the tank. Figure 6-23 is a schematic representation of a plug flow activated sludge system. Inspection of Figure 6-23 indicates some of the possible problems caused with the plug flow system. The major problem is that all of the incoming raw waste to be treated and the recirculated sludge flow are introduced at one point at the influent end of the basin. Because of this fact, it can be seen that it is at the influent end of the basin that the highest demand for dissolved oxygen occurs, whereas the dissolved oxygen is distributed uniformly down the length of the tank. Consequently, the plug flow system has the disadvantage of not being able to supply sufficient oxygen at the influent end of the tank during periods when even moderately high waste loads are introduced.

b. step aeration. Step aeration was developed as a modification to the plug flow system in order to overcome the problems caused by insufficient dissolved oxygen being present at the influent end of the tank. In this process, waste enters the aeration tank at a number of different points; but all of the returned sludge is introduced at the point of first entry, with or without a portion of the incoming raw waste. The sludge solids concentration in the mixed liquor within the aeration basin is, therefore, greatest at the first step or point of entry and decreases as more waste is introduced at subsequent steps. This provides a means of ready regulation of the total amount of solids held under aeration. In this process treatment practically equivalent to the plug flow activated sludge process can be attained in about half the aeration time while maintaining good operation. Figure 6-24 illustrates this system.

c. tapered aeration. This process as illustrated in Figure 6-25 was developed on the theory that the greatest amount of air is needed during the early part of the aeration period. Air is therefore introduced into the waste at a higher rate in the inlet section of the aeration tank than in subsequent sections to roughly approximate the oxygen utilization in the various sections or stages of aeration within the aeration basin. The advantages claimed for this modification of the plug flow activated sludge flow process are a better control of a process in meeting shock loads and a reduction in the cost of operation.

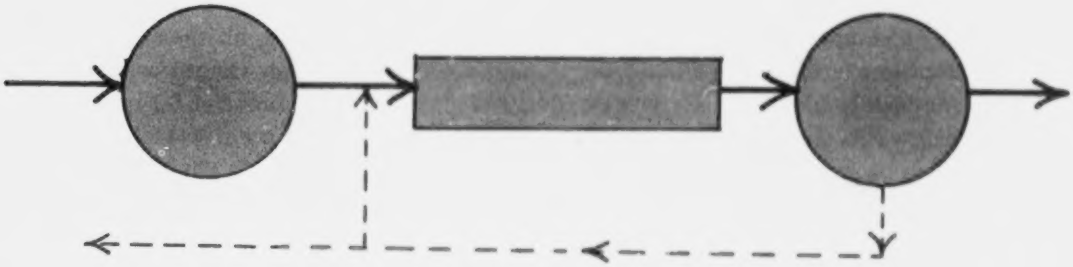


Figure (6-23)
Conventional or Plug Flow Activated Sludge
System Schematic

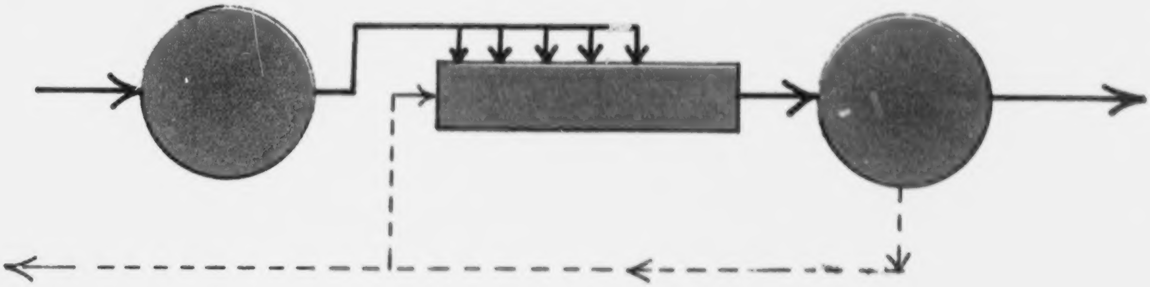
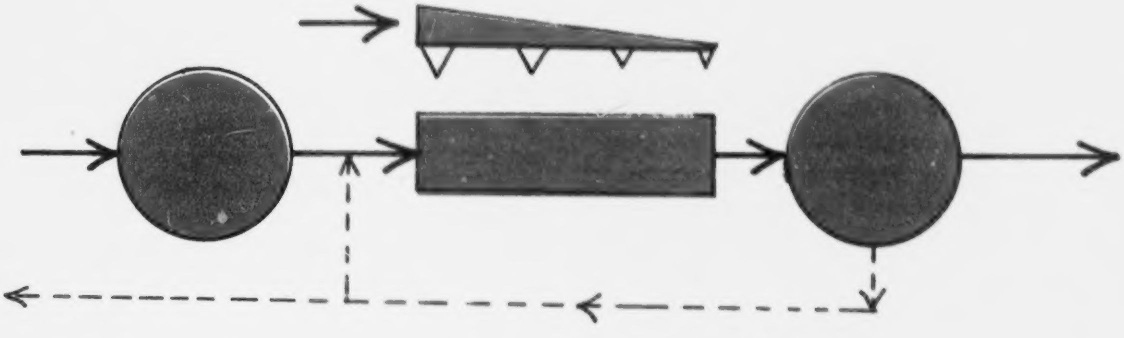
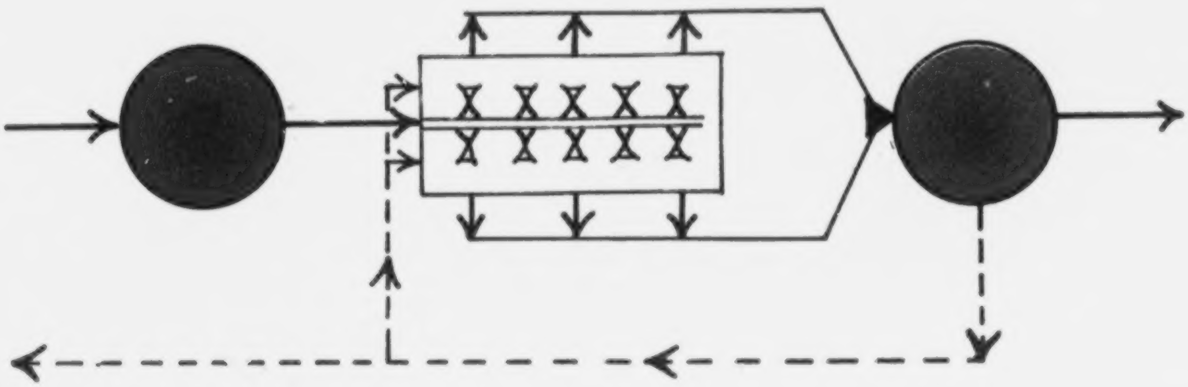


Figure (6-24)
Step Aeration Activated Sludge System
Schematic



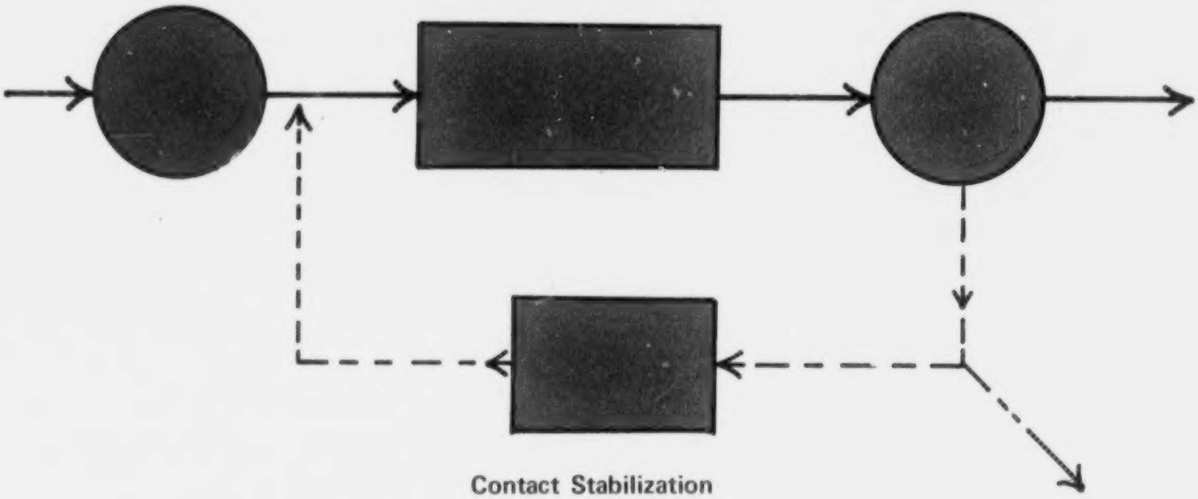
Tapered Aeration
Figure (6-25)
Typical Mechanical Aerators

d. complete mix. Recently, as the theory behind activated sludge treatment has become more widely investigated, a relatively new type of system termed complete mix has been developed. In the complete mix type of operation, an effort is made to completely and intimately mix all of the raw incoming waste throughout the entire volume of the aeration basin as quickly as possible. In this manner, the entire contents of the aeration basin are caused to be as homogenous as possible and accordingly, the amount of oxygen required for treatment should theoretically be the same in all portions of the aeration basin. Advantages of this type of treatment are that less total oxygen is required because oxygen concentration is maintained constant throughout the entire tank volume and thus localized high oxygen concentrations are avoided. The process provides for immediate distribution for all incoming waste loads throughout the entire volume of the tank, thus minimizing the effect of slug loadings caused by occasional discharges of very strong wastes or short-term, high-volume waste discharges. Figure 6-26 illustrates this system.



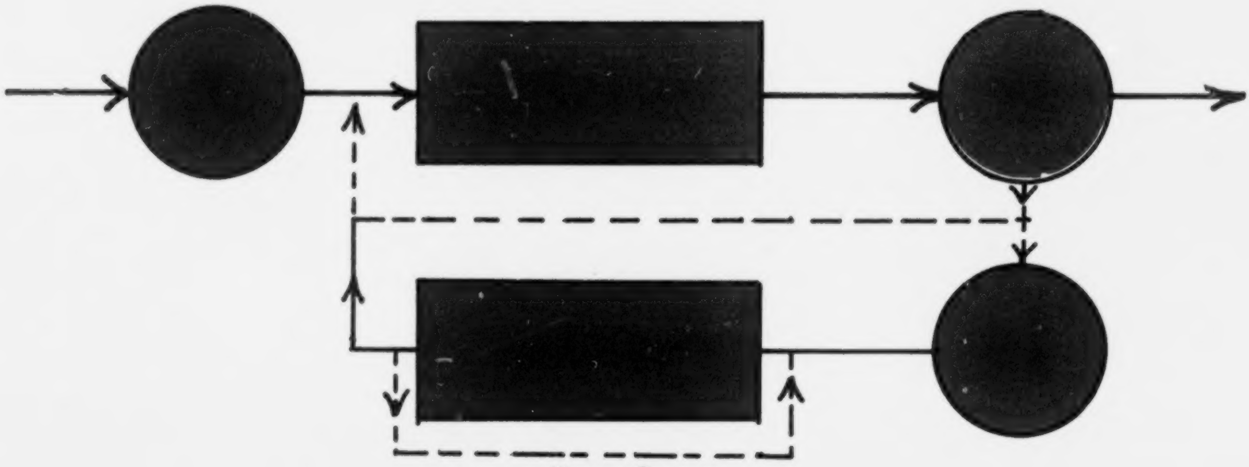
Completely Mixed Activited Sludge System
Figure (6-26)

e. contact stabilization. In the contact stabilization, incoming raw wastes are mixed with return sludge in a contact basin for a period of from 30 minutes to one hour. Theory behind the contact stabilization modification indicates that activated sludge organisms initially absorb nearly all of the BOD contained in the raw waste. Only after this initial absorption has occurred do the organisms actually convert the absorbed BOD into new cell material. In the contact stabilization modification as illustrated by Figure 6-27 the organisms after the absorption phase is completed, are settled and pumped into a so-called stabilization basin wherein they are aerated for periods of from 6 to 24 hours. Therefore a much smaller aeration basin can be used. Advantages claimed for the contact stabilization modification include smaller total volume of aeration basin and lessened operating costs. This modification has been used in a number of old, overloaded, plug flow systems and has resulted in the increasing of capacity in existing activated sludge plants without construction of additional aeration basins. The contact stabilization process may be particularly well adapted to types of waste which have a high percentage of soluble BOD, and for this reason many of the contact stabilization plants presently being designed do not use pretreatment by primary sedimentation ahead of the aeration system. One major drawback of the contact stabilization system, is that detention times in the contact aeration basin must be rather closely controlled. If the return sludge and wastes are allowed to remain in this basin for too long a period of time, desorption occurs. Thus overall treatment efficiencies can be reduced. Furthermore, if the contact time is not sufficient, absorption does not occur fully and again treatment efficiencies are drastically reduced.

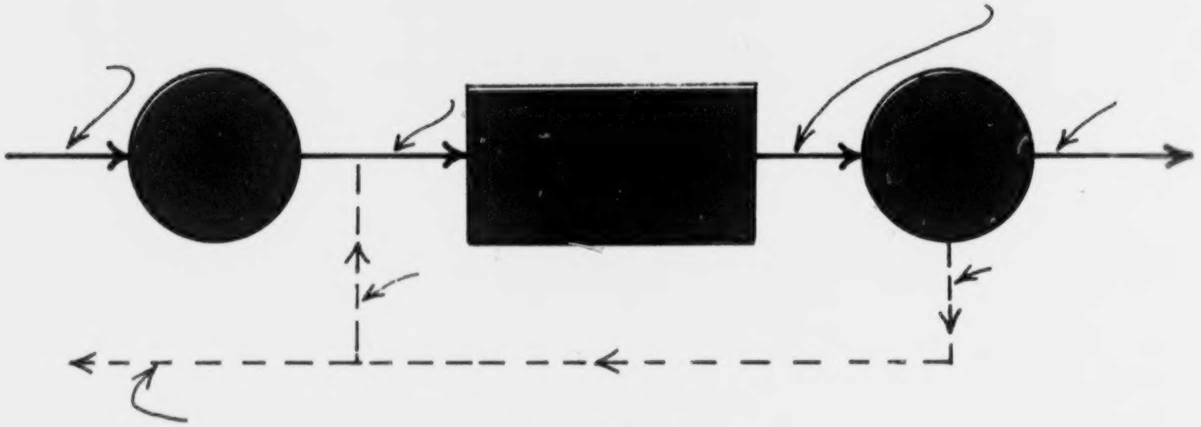


Contact Stabilization
Figure (6-27)

f. Krause process. The Krause process is a modification to the plug flow activated sludge system which has been successfully used in a few instances where the incoming wastes had insufficient nutrients available to provide a stable activated sludge flow. The process was developed by an operator in Peoria, Illinois for use on industrial wastes from the operation of a bourbon distillery in Peoria. The type of waste to be treated at Peoria had a nitrogen deficiency. Because of this, proper operation of the original plug flow system could never be achieved. The operator of this plant, noticing that it was very difficult to obtain a sludge which would settle readily in his final sedimentation basins, reasoned that if sludge and supernatant from his anaerobic digesters were added to the aeration basin, a more dense activated sludge might be created which in turn might settle more efficiently in his existing sedimentation basins. In experimenting by adding digester supernatant and sludge to his process, the operator found that not only was a much more settleable activated sludge produced, but that overall treatment efficiencies were remarkably improved. After considerable experimentation on the part of the plant operator it was determined that the addition of the digester supernatant and digested sludge solids had two beneficial effects; mainly it provided the activated sludge system with a ready source of nitrogen and also tended to weight the sludge thus providing better settling characteristics. Various modifications have been made to the Krause process which include the addition of nitrification basins which function in much the same manner as the stabilization basin provided as a part of contact stabilization as previously described. The Krause process is illustrated by Figure 6-28.



Krause Process
Figure (6-28)



Extended Aeration
Figure (6-29)

g. extended aeration. Another modification of the activated sludge process is termed the extended aeration process. In reality, the extended aeration process is nothing more than a low rate complete mix activated sludge plant in which approximately 24 hours detention time are provided. Due to the extremely long aeration period, the build-up of active solids is extremely slow and the great majority of all solids are destroyed by what actually amounts to aerobic digestion. Because of this, very little waste sludge must be removed from the system. Many small extended aeration plants operate with the only sludge wasting occurring as the natural loss of solids from the final sedimentation basin. Figure 6-29 illustrates a typical extended aeration system.

(5) definition of terms. Because of the complexity of activated sludge treatment processes, a large number of terms are used in order to describe the system. Many of these terms have rather complicated sounding names and the standard definitions available in many textbooks are likewise quite complicated. For the purposes of this basic operator's manual an attempt is made herein to define the more common of these terms in understandable language. For the purposes of conforming to accepted terminology, it is best to retain the accepted names for the various terms; however, the definitions in most cases have been simplified.

Mixed Liquor. This term refers to the entire homogenous contents of an aeration basin. In simplified terms, if an operator dipped a bucket into an aeration tank, he would then have a bucket filled with mixed liquor.

Return Sludge. Return sludge is the term given to the settled solids from a final sedimentation basin following an aeration basin. These solids are returned to the aeration basin.

Waste Sludge. Waste sludge is the term given to the portion of settled solids from the final sedimentation basin which are removed from the activated sludge system to be given further treatment before disposal. In other words, the waste sludge is that portion of the settled solids which is removed from the activated sludge system.

Recirculation Ratio. In order to recirculate the return sludge to the aeration basin, it is necessary to pump some volume of return sludge. The quotient obtained by dividing the volume of the returned sludge by the volume of the incoming raw waste flow is termed the recirculation ratio. For example, if a small activated sludge plant received a raw waste flow of 1,000 gallons per hour, and it was necessary to pump 250 gallons per hour of returned sludge, the recirculation ratio would be 250 divided by 1,000 or 25 percent.

Mixed Liquor Suspended Solids (MLSS). This is a term which is used to express the concentration of suspended solids within the mixed liquor. If a one-liter sample of mixed liquor were filtered and the material caught on the filter paper were dried and weighed, the mixed liquor suspended solids concentration would be numerically equal to the grams of dried solids filtered from one liter of mixed liquor. For example, if one liter of mixed liquor were filtered and the residue, dried and weighed, was found to weigh 3,000 milligrams, the mixed liquor and suspended solids concentration would be equal to 3,000 milligrams per liter.

Sludge Volume Index. This is a term which expresses the volume in milliliters which is occupied by one gram of solids in the mixed liquor after a 30-minute settling period. It is computed by dividing the volume occupied by settled sludge after 30 minutes of settling time by the mixed liquor suspended solids concentration and multiplying that quotient by 1,000. For example, assume that the mixed liquor in an aeration basin is tested and found to contain a solids concentration of 3,000 mg/l. If a sample of this mixed liquor is then collected and allowed to settle for a period of 30 minutes in a graduated cylinder and if the volume of the settled sludge, after 30 minutes, is found to be 300 milliliters, the sludge volume index may be computed as

$$\frac{300}{3000} \text{ X } 1000 = 100$$

The sludge volume index of this particular aeration basin mixed liquor would therefore be 100. The sludge volume index is particularly important because it expresses numerically, the tendency for sludge to exhibit either good or poor settling characteristics.

Sludge Density Index. Sludge density index is another term used to express the settling characteristics of activated sludge. It is numerically equal to 100 divided by the sludge volume index. For example, the sludge density index of the mixed liquor described immediately above would be numerically equal to 100 divided by 100 or 1. From this it may be seen that if a mixed liquor has a sludge volume index of 100, the sludge density index would be 1; or if a mixed liquor had a sludge volume index of 200, the corresponding sludge density index would be equal to 0.5, etc.

Load Factor. Load factor is a term which relates the concentration of available food to the concentration of organisms available for treatment. The load factor is equal to the pounds of BOD present in the influent to the aeration basin per day divided by the pounds of mixed liquor suspended solids under aeration. Load factor is always expressed as pounds of BOD per pound of mixed liquor suspended solids per day. In order to determine load factor, it is necessary to calculate the total weight of solids contained in the mixed liquor at any one time. This may be accomplished by multiplying the volume of the aeration basin expressed in millions of gallons times the mixed liquor suspended solids concentration in ppm times 8.34. The result of this calculation, is numerically equal to the pounds of mixed liquor suspended solids under aeration.

Oxygen Uptake Rate. This term is used to express the rate at which oxygen is consumed by an activated sludge system. There are a number of ways of expressing this particular rate, the most common of which is to express the actual pounds of oxygen used per hour. For example, if an activated sludge plant actually used 24,000 pounds of oxygen per day, the oxygen uptake rate for this particular plant would be 1,000 pounds of oxygen per hour. In some cases, oxygen uptake rates are expressed in other terms such as milligrams per liter oxygen per hour. However, the important thing to remember is that uptake rates no matter how they are expressed simply are an indication of the rate at which oxygen is consumed in an activated sludge system.

Sludge Age. This term is used to express the length of time in days that the average particle of activated sludge remains in the system before being wasted. As with many other of the common terms used in describing the activated sludge process, the term sludge age has been defined in a number of different ways. Many of the definitions given in textbooks for sludge age are completely meaningless and should be disregarded. Sludge age is numerically equal to the quotient obtained by dividing the pounds of mixed liquor suspended solids under aeration by the pounds of dry solids wasted from the system per day. The sludge age is particularly important in describing activated sludge processes because it provides a rapid numerical indicator of the activity to be expected from the system. For example, if an aeration basin had a volume of 100,000 gallons and contained a mixed liquor suspended solids concentration of 1,000 milligrams per liter, there would be a total of 834 pounds of mixed liquor suspended solids under aeration. If this system were operated with sludge being wasted at the rate of 83.4 pounds of dry solids per day wasted, the sludge age would be 10 days.

Active Metabolism. This is a term used to describe the life processes of activated sludge organisms which occur when the activated sludge organisms are in an active growth phase as described previously.

Endogenous Metabolism. This is the term used to describe the life processes of activated sludge organisms during the time that they are in an endogenous growth phase; that is, during the time when the growth is such that no net cell production occurs and the organisms are actually utilizing their own cell material as a source of food.

Food to Microorganism Ratio. This is another term sometimes used to describe loading on activated sludge treatment systems. It is defined as the quotient obtained by dividing the pounds per day of available food (BOD) in the aerator influent by the pounds of mixed liquor suspended solids under aeration.

Nitrification. This is a term used to denote the process which occurs when nitrogen in the form of either ammonia nitrogen or nitrite nitrogen is oxidized to the nitrate stage. In years past, it was commonly accepted that well-operated treatment plants should essentially convert all of the nitrogen present in the raw incoming wastes to the nitrate form. The old, commonly used relative stability test was actually a measure of nitrification since it measured the ratio of oxygen contained in nitrites and nitrates to the total oxygen required to satisfy the long-term BOD of a treatment plant effluent. One of the main reasons that nitrification was thought to be favorable was that highly nitrified effluents provided a ready source of chemically-bound oxygen which was available to organisms in receiving waterways. This helped to prevent septic conditions from occurring in receiving streams. Where receiving streams have little flow and in plants where no effort is made to remove nitrogen in order to reduce the nutrient value of effluent, it is probably still desirable to produce an effluent as highly nitrified as possible.

Denitrification. As can be inferred from the term denitrification, this is the name given to the process which occurs when chemically-bound oxygen from either nitrates or nitrites is stripped away for use by biological organisms. The stripping away of this chemically-bound oxygen results in the formation of nitrogen gas. Nitrogen gas is relatively insoluble and is released in the form of tiny bubbles from liquids in which denitrification is occuring. The liberation of this nitrogen gas is not particularly detrimental, however, it has an extremely harmful side effect. The tiny nitrogen gas bubbles tend to clump together under bits of sludge or floc in final sedimentation basins, thus causing these particles of sludge or other solid material to rise to the surface of the tank. Sludge which rises to the surface of the tank is said to be gas-lifted and usually overflows the final clarifier basin weirs. In the effluent it reduces the effective pollution removal by the treatment plant by increasing the BOD and solids content of the effluent.

(6) equipment. Equipment required for the activated sludge process includes aeration basins or tanks, oxygen transfer devices, devices for distributing incoming flow to the aeration basin, equipment for distributing return sludge flow to the aeration basin, equipment for settling out solids from the mixed liquor, and equipment for returning these solids as returned sludge as well as wasting excess sludge.

Aeration basins or tanks come in many different shapes and forms depending upon the various types of activated sludge systems to be used. Most commonly, aeration basins are constructed of reinforced concrete, and in the case of most older plug flow systems are usually about 15 feet deep and have a length of at least five times their width. Newer complete mix type activated sludge aeration basins take various configurations depending upon the type of aeration equipment to be used. However, in general these aeration basins are also constructed of reinforced concrete and are approximately 15 feet deep. Complete mix aeration basins tend to be more square in shape; however, in some instances, long, narrow basins are also used with this system.

There are a large number of manufacturers engaged in manufacturing so-called package activated sludge plants. These package plants are generally constructed of steel and the aeration basin sections tend to be rectangular in shape. For the most part the package plants are generally rather small and are not designed to treat large BOD loads since it is common practice to provide a detention time in the aeration basin section of approximately 24 hours. A few manufacturers make larger package plants and in some cases these plants have circular aeration basins.

In the aerated lagoon type of activated sludge process, which appears to be finding more and more acceptance for use particularly where industrial wastes are involved, aeration basins generally take the form of an earth pond about 10 feet deep provided with dikes around the periphery. In some cases, the ponds are lined with an impervious material such as gunite concrete or a bentonite clay mixture. In other cases it is not necessary to line the pond bottoms. Common practice seems to be to provide some sort of slope protection such as riprapping along the faces of the dikes in the vicinity of the normal water line in order to resist erosion caused by wave action. The aerated lagoon type of aeration basin, being relatively inexpensive to construct, is frequently designed for detention times in excess of 24 hours.

Aeration basin geometry, that is shape, is affected by the type of aeration equipment to be used. As was previously discussed it is necessary to provide a high degree of mixing within an aeration basin in order to carry out the activated sludge process satisfactorily; and accordingly, the design of aeration basins must be such that this degree of mixing can be imparted by the aeration devices. For this reason, aeration basins in which single mechanical type aerators are placed, generally tend to be circular or square in shape with the aeration device being placed in the center. Aeration basins which are equipped with multiple mechanical aeration devices can be either square or rectangular in shape with the area served by each mechanical aerator roughly square in shape. For example, if three surface aerators were to be used in an aeration basin, one acceptable configuration might be an aeration basin having a length three times its width. In this manner, each surface aerator would actually be operating in a square and the entire tank might be thought of as three squares placed end to end. Aeration basins using diffused air aeration systems tend to be long and narrow in cases where the air diffusers are placed along one wall of the tank. The narrow width is dictated by the fact that diffused air aeration equipment is not capable of rolling or mixing tanks much wider than 25 feet. In other cases using diffused air aeration equipment, the aerators are placed crosswise to the length of the tank and under these circumstances there is no limit to the width which can be aerated and in this case the entire aeration basin might be thought of as a series of rectangles placed side to side in order to form a long basin. If this is done it is necessary to span the width of the basin with some sort of platform in order to support the diffused air aeration equipment and it is the structural limitations of this bridge which determines the maximum practical width of the tank.

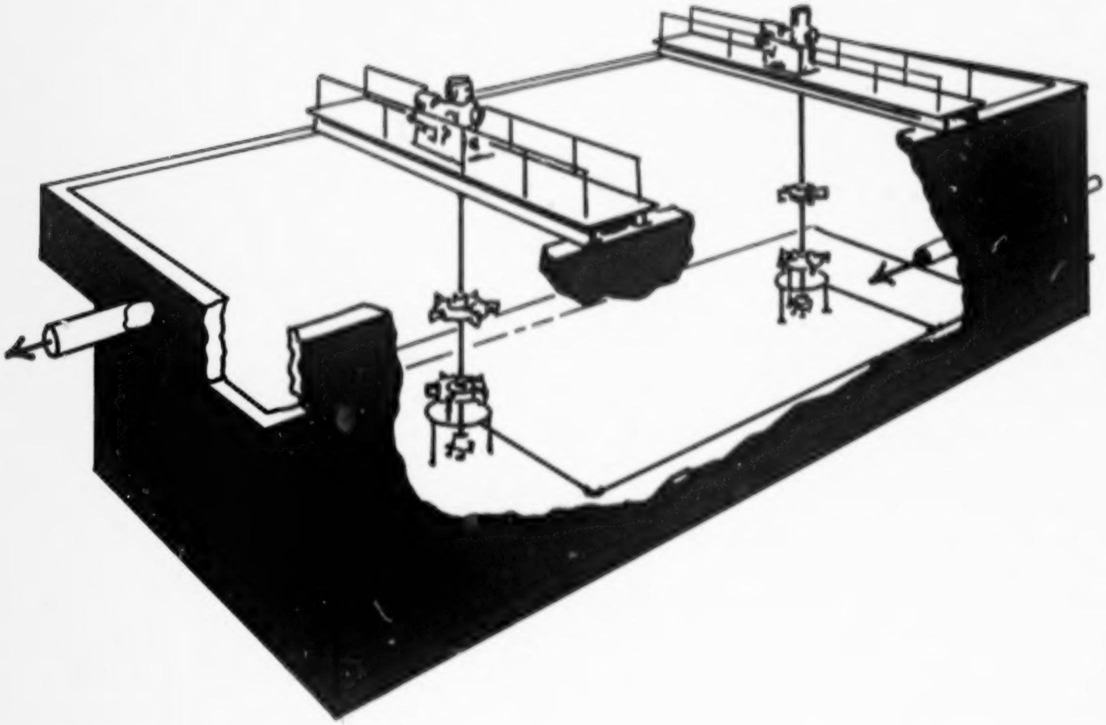
There are four main types of oxygen transfer equipment presently being used in activated sludge systems. These are mechanical aerators, both horizontal and vertical; sparged turbines; coarse bubble diffused air; and fine bubble diffused air.

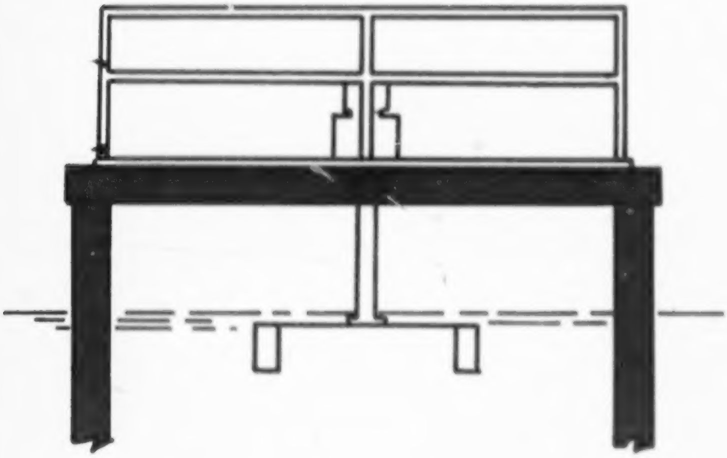
Mechanical aerators are manufactured by many different companies and are available in a number of different configurations. Figure 6-30 and 6-31 illustrates several of the different types of equipment available. Mechanical aerators may be mounted on bridges spanning aeration basins, may be mounted on supporting structures in the center of aerated lagoons or may be floated either on rafts or by means of plastic floats constructed as a part of the aeration device.

Sparged turbine type aerators are really a combination of mechanical and diffused air equipment. In general the sparged turbine consists of one or more sets of paddle wheels rotated in the horizontal plane beneath the surface of the liquid to be aerated by means of a vertical shaft driven by a gear box and electric motor mounted above the surface of the aeration basin. Under the rotating paddle wheels, compressed air is discharged from one large opening or from a series of orifices drilled in a so-called sparge ring. This air, released under the center of the paddle wheels, rises vertically upward until it encounters the rotating paddle wheels which tend to beat the large air bubbles into many very small air bubbles. Manufacturers of this type of equipment claim that the mechanical shearing action provided by the rotating paddle wheels increases the transfer efficiency of oxygen from the air supplied; and that because of this fact, total overall horsepower demand is in some cases reduced.

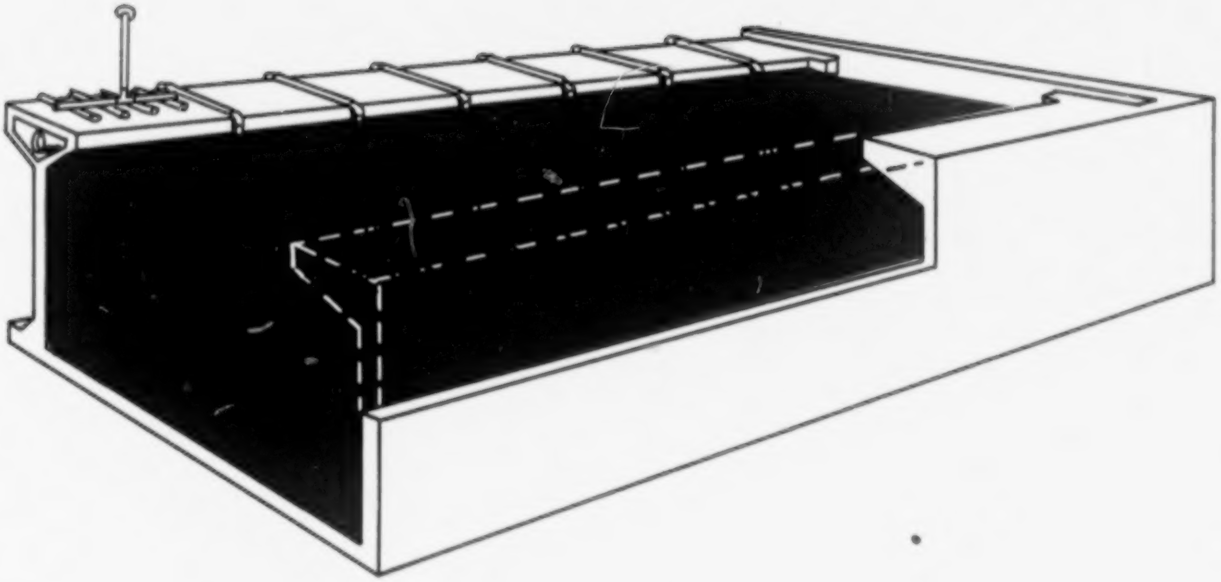
Completely diffused air systems may be either of the fine bubble or coarse bubble type. The coarse bubble type of diffused air equipment releases the compressed air in relatively large bubbles which rise rapidly to the surface of the tank thus causing a pumping and mixing action within the aeration tank. Because the coarse bubble equipment does not utilize very small openings through which the air enters the aeration basin, this type of equipment is not easily plugged and is usually permanently installed near the bottom.

Fine bubble aeration equipment releases the compressed air as a series of very fine or small air bubbles by passing the air through some material





Mechanical Aerator
Figure (6-30)



Mechanical Aerator
Figure (6-31)

which is porous enough to allow passage of the air such as carborundum blocks, synthetic cloth materials and in some cases various plastics. Because the compressed air must bubble through very small openings, it is necessary that the compressed air supply be very thoroughly filtered and cleaned prior to its passage through the diffusion device. Even with the best available cleaning equipment, it is necessary to periodically clean the diffusion devices used in fine bubble aeration and for this reason they are usually installed in such a manner that they can be lifted from beneath the surface of the tank without completely dewatering the tank. While fine bubble aeration devices have the disadvantage of requiring air filtration and periodic cleaning, they have the advantage of transferring more oxygen per unit volume of compressed air than do the coarse bubble devices.

Flow distribution devices commonly used in activated sludge treatment vary according to the type of system being used. In the case of older plug flow systems, common practice was to simply introduce the flow at one end of the long narrow basin providing very little in the way of baffling in order to distribute the flow. It was not considered necessary to baffle the incoming flow because of the mixing action provided by the aeration devices. One problem which has arisen in many cases, because of the lack of baffling in older plug flow systems is that the incoming flow tends to flow down the center of the tank along the center of the axis of rotation caused by the aeration equipment. Because of this some tanks have short-circuited rather badly and it has been necessary to construct baffles in order to prevent this short-circuiting. In the case of complete mix systems, attempts are made to distribute the flow in such a way as to aid in complete mixing throughout the entire volume of the tank as rapidly as possible.

Several methods have been employed including the use of multiple feed points along one entire side of a basin. In the complete mix system, it makes very little difference as to where the flow is actually introduced as long as it is introduced in a manner which will promote complete mixing throughout the entire volume of the tank. In the case of step aeration, incoming flows are divided into a number of influent points and controls are generally provided so as to adjust the flow into the tank at any given point.

Return sludge flow distribution, in most cases has been accomplished by mixing the return sludge flow with the incoming flow to the aeration basin prior to releasing the entire mixture. In the case of step aeration, however, the return sludge flow is usually kept separate and introduced at a single point near the influent end of the basin. In any event, it is usual practice to design return sludge flow distribution in such a way to ensure that the return sludge flow will enter the aeration basin as quickly as possible.

Sludge return and wasting equipment is vital to the success of any activated sludge plant. This equipment has frequently been improperly designed to do the necessary job. Many older activated sludge plants were designed for a maximum sludge return capability of only about 30 percent of the incoming flow. Some of these plants have been unable to return sufficient sludge to maintain desirable mixed liquor suspended solids concentrations in the aeration basin. Later activated sludge plant designs, particularly those incorporating the complete mix theory, have usually provided a return sludge capability of from 50 to 100 percent of incoming flow with the higher value being more common.

The current thinking concerning this matter is that sludge should be settled from the mixed liquor as rapidly as possible and returned immediately either to the aeration basin in the case of conventional systems or to a nitrification basin in the case of certain modified systems such as the Krause process. Since the return sludge is highly active, it has a rapid oxygen uptake requirement and cannot usually be allowed to become void of oxygen without denitrification. For this reason, the rapid sludge removal or the sludge suction type of final sedimentation basin is preferred because this type of equipment allows the operator to remove the active solids from the aeration basin effluent in a very rapid manner. It is usual practice to utilize pumps to return sludge to the aeration basin. Generally speaking, centrifugal type pumps have proven to be satisfactory because the return sludge does not have particularly stringy characteristics. It is quite important that facilities be available so that the operator can accurately judge the amount of sludge being returned to the system as well as the amount of sludge which is being wasted. For this purpose weir boxes and in some cases magnetic flowmeters are used to measure the respective flows.

Measurement of the total amount of solids wasted from any activated sludge system is particularly important since if insufficient solids are wasted, the entire system can be rapidly overloaded and if too many solids are wasted it will be impossible to maintain desirable levels of mixed liquor suspended solids. Many activated sludge plants waste sludge only on an intermittent basis; however, this practice can tend to place undesirable loads on waste sludge handling equipment. In the case of long detention time aeration systems, it is probably satisfactory to waste on an intermittent basis because the total volume of solids to be wasted is relatively small. In the case of high rate activated sludge systems, it is much preferred to waste sludge on a continuous basis primarily because the amount of solids which needs to be wasted is relatively high, and equipment for handling these waste solids could be heavily overloaded if sludge wasting was done on an intermittent basis.

C. Lagoons and Oxidation Ponds.

(1) purpose. The purpose of lagoons and oxidation ponds (variously called waste stabilization ponds or raw sewage lagoons) is to accomplish purification of wastes utilizing the same biological mechanisms normally present in lakes and streams. The principal difference between a lake or stream and the lagoon system of treatment is that the lagoon system of treatment is carried out under controlled conditions in an impoundment of relatively large size. A theoretical detention time of 90 days or more is usually provided.

(2) theory. The sewage lagoon is essentially a large, relatively shallow body of water into which untreated or partially treated sewage is introduced and retained for a time sufficient to permit stabilization of pollutants by complex natural processes involving sunlight, oxygen, water currents, algae and bacterial action. The lagoons are usually designed so as to provide sufficient waste dilution and aeration to ensure that the surface liquid strata will remain aerobic. The bottom layer of most ponds contains materials which have settled from the incoming waste flow and is usually void of dissolved oxygen. An overlying layer of oxygen-containing liquid, however, prevents nuisance conditions from occurring in most cases.

(3) pretreatment. Ponds may be operated without benefit of any pretreatment by simply allowing the raw incoming waste flow to discharge into the pond. In some cases, it has been found advantageous to provide grinders to at least shred the major solids prior to their discharge into ponds receiving raw wastes. In other cases, ponds are designed to receive the effluent from either primary or complete secondary treatment plants. In these

cases, the ponds are commonly referred to as oxidation ponds and serve the major purpose of polishing the effluent in order to achieve a higher removed percentage of pollutants.

(4) classification. Ponds may be classified according to the type of waste flow they receive, that is, either raw waste or treated waste; according to the number of individual cells provided and the type of operation, whether in series or parallel; or according to whether or not an effluent is discharged.

Ponds receiving raw wastes are generally termed waste stabilization ponds or raw sewage lagoons and are usually designed on the basis of BOD load per unit of surface area. In general, a loading of approximately 60 pounds of BOD per acre of surface area per day has been considered to be the upper limit for use in the State of Washington. Ponds receiving treated effluent are generally termed oxidation ponds or polishing ponds and are also designed on the basis of BOD loading per unit of surface area.

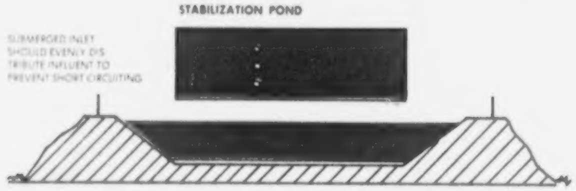


Figure (6-32)

Oxidation ponds tend to be constructed as a single cell since they follow secondary treatment processes. Recently, there has been a tendency to design oxidation ponds or polishing ponds as a series of cells which overflow from one pond into another because it has been demonstrated that reductions in the amount of algae discharged in the final effluent can be accomplished in this manner. Waste stabilization ponds or ponds receiving raw wastes, generally consist of more than one cell and may be operated in either series or parallel. During times when particularly strong wastes are encountered, it is common practice to divide the flow so that each cell receives a portion of the total incoming flow according to its particular size as determined by surface area. This is usually done in cases where series operation would result in overloading the first pond in the series and the formation of septic conditions. In installations providing three or more cells, it is common practice to operate the system in such a way that the wastes, after passing through one or more ponds in parallel, is collected and passed through the remaining pond or ponds in series flow. Under these conditions, the ponds which first receive the sewage flow are often termed primary cells and the ponds which receive effluent from the primary cells are often termed secondary cells. Operation in this manner tends to reduce the amount of algae discharged in the final effluent.

When ponds are located in areas which do not receive significant rainfall and in which evaporation is quite high, it is possible that there will be no effluent from the ponds since the combination of percolation of some water into the underlying soil and the evaporation may equal or exceed the total amount of liquid flowing into the ponds. This type of pond is referred to as a non-overflowing pond. In most cases, however, climatic conditions will be such that ponds will produce an effluent for discharge into a receiving waterway.

(5) equipment. Very little in the way of mechanical equipment is required for the pond type of treatment. Basically, the requirements are such that only influent and effluent piping and inter-connecting piping and control boxes to control water level in the various cells are required. The ponds themselves are usually constructed either by excavating a depression or by building dikes from earth to enclose the ponds. Earth dikes are usually used to divide the entire area into the required number of cells and the earth dikes are usually seeded to various grasses in order to control erosion. In some cases, particularly in very large ponds, it is necessary to riprap the dike slopes in the vicinity of the normal water line, in order to prevent erosion by wave action. If dikes are seeded with various types of grasses it becomes necessary to provide some sort of mowing machinery in order to control the vegetation. For this purpose, small farm type tractors equipped with sickle-type bar mowers have proven to be quite satisfactory unless

the dike slopes are so steep so as to prevent operation of equipment on them.

D. Anaerobic Sludge Digestion.

(1) purpose. Anaerobic sludge digestion has four main purposes which may broadly be defined as follows: To destroy or control effectively, sources or agents of disease and infection; to decompose the highly putrescible organic matter contained in sludges to relatively stable or inert organic or inorganic compounds; to reduce the volume of solids to be handled by removal of some or all of the liquid portion; and to utilize by-products of the anaerobic sludge digestion process in order to minimize overall cost of operation.

(2) theory. Anaerobic sludge digestion is carried out in the absence of free oxygen by anaerobic organisms. In the process, living organisms break down the complex molecular structure of the solid materials removed from wastes, setting free much of the water content of the solids and obtaining nutritional and energy requirements for their life processes by conversion of the putrescible solids into more stable organic and inorganic solids.

In theory, the process of anaerobic sludge digestion may be thought of as occurring in three different phases. The first phase which occurs rather rapidly is termed acid fermentation. In this phase the microorganisms attack soluble or dissolved solids in the sludge fed to the digester breaking these substances down into more simple organic acids (volatile acids). The term acid fermentation refers to the liberation of organic acids within this first stage of digestion. The end products of this first stage of digestion being acid in nature tend to lower the pH of the liquid mass in the digester and if other stages of digestion did not occur simultaneously, the entire process would be stopped by the production and liberation of the organic acids referred to above.

The second stage of anaerobic digestion is termed acid regression. In this stage the organic acids liberated in the first stage, as well as nitrogenous compounds are attacked by other microorganisms. During this particular stage pH tends to rise as the soluble organic acids are decomposed.

The third stage of anaerobic digestion is termed the methane production stage and occurs simultaneously with the first two stages. Methane bacteria attack organic acids and other degradation products from the first two stages to form methane and carbon dioxide gases. The methane gas evolved, is a highly flammable gas and has a considerable fuel value which can be utilized as a source of power or heat.

Solids remaining in the anaerobic sludge digestion process after the third stage of digestion is completed are relatively stable and can be disposed of on land areas in liquid form or as dried sludge. These solids have some minor fertilizer value and in addition can be a valuable soil conditioner when used in soils having a high clay content.

For proper operation of anaerobic sludge digesters, it is necessary to operate the system in such a way that all three stages of digestion occur simultaneously. If this is not done, the second and third stages of digestion would occur only very slowly if at all, because of the adverse pH conditions which are created by the first stage of digestion.

The whole digestion process might be better understood if it were likened to a factory production line where one group of workers takes certain raw materials and conditions these materials so that a second group with different skills can convert the material for a specialized third group of workers who turn out end products.

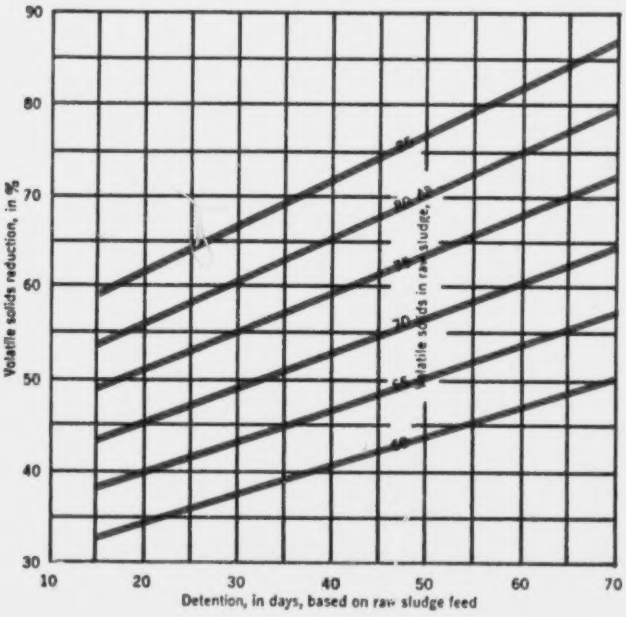
The bacteria responsible for the third stage of the normal sludge digestion process are extremely pH dependent and optimum third stage digestion cannot occur unless a pH of approximately 6.8 to 7.4 is maintained. In addition to being pH dependent, the methane bacteria are temperature dependent and under normal circumstances function at their best in a narrow temperature range of 90 to 98 degrees Fahrenheit. They are extremely sensitive to sudden changes in temperature and temperature fluctuations of as little as 3 degrees Fahrenheit over a short period of time can upset the process.

The operation of anaerobic sludge digestion depends primarily and fundamentally on the reduction of the volatile content of the sludge fed to the system. It is generally observed and accepted by operators that a well-digested sludge has a volatile content of about 40 to 45 percent. Reduction to this level can be achieved in well designed and operated digestion facilities which are not overloaded and which are free from interference of toxic substances. The percentage of volatile matter remaining in well-digested sludge appears to be fairly independent of the percentage of volatile material in the original sludge; however, more digester capacity normally is required for highly volatile raw solids than for solids having a low volatile content.

The reduction of volatile material in the original sludge feed, in a properly operated digestion system depends on four main factors as follows: food supply (volatile solids in the sludge fed), time; temperature; and mixing.

Organisms responsible for anaerobic digestion appear to operate most efficiently when sludge is fed to the system in small quantities at frequent intervals. If digesters are fed infrequently but in large amounts, the first or acid fermentation stage tends to predominate thus causing an unfavorable pH condition and restricting the second and third digestion stages.

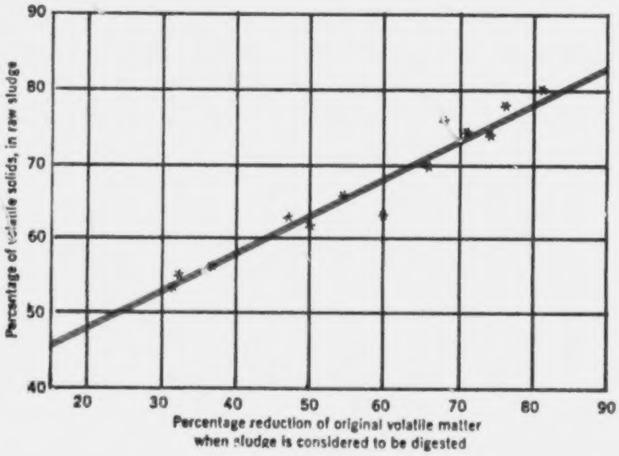
Anaerobic sludge digestion proceeds in almost any range of temperature likely to be encountered, but the time required for satisfactory volatile solids reduction varies greatly with temperature. Detention time also varies with the percentage of volatile matter in the original sludge added to the digester. These relationships are shown in Figures 6-33 and 6-34. The curves shown in Figure 6-33 have been derived from data on anaerobic sludge digestion tanks operating at temperatures in the range of 85 to 90 degrees without significant mixing. In tanks equipped with proper mixers, the entire process can be speeded up considerably.



-Reduction in Volatile Solids in Raw Sludge, for Detentions from 15 to 70 Days, T = 85° to 95°F

Figure (6-33)

Reduction in Volatile Solids vs. Digestion Time



-Reduction in Volatile Matter by Digestion

Figure (6-34)

Reduction in Volatile Solids Required for Complete Digestion

It is of interest to note that during the first 10 days of digestion, the rate of destruction of volatile matter is extremely fast when compared with the rate which occurs after approximately 10 days. During the early period of high volatile solids reduction, tremendous volumes of methane and other gases are liberated. The activity within the digester is so violent during this period that separation of liquid from the digesting solids is extremely difficult. After approximately 10 days the rate of gas production and activity slows down considerably and under these conditions, it is much easier to separate liquid from the solids and to compact the solids. For this reason, digestion is quite often carried out in two separate tanks with all of the original sludge being fed into the first tank in series. This first tank is usually called the primary digester, and it is in this digestion tank which most of the gas production takes place. Since the primary tank is subject to great activity because of the high rate of gas production, it is normal practice to install mixers and temperature control equipment in order to speed up the actions which occur in the primary digester. The mixed liquor contained in the primary digester is then allowed to overflow into a second digestion tank which is normally referred to as a secondary digester. There the gas production proceeds at a much slower rate; and accordingly, favorable conditions are established in order to promote separation of liquid from the digested solids and to allow compaction of the digested solids in the bottom portions of the tank.

Effective mixing of the incoming sludge with the contents of the digester is necessary to provide all working organisms with their essential food supply and to maintain a uniform temperature throughout the digester. As previously stated, mixing is generally only carried out in primary digesters since it is desirable for the purposes of solids separation to maintain secondary digesters in as quiet a condition as is possible.

(3) pretreatment. Because the anaerobic sludge digestion process is time dependent, it follows that for a given required detention time, a sludge containing as little water as is possible is desirable since total required volume to provide a given detention can be remarkably reduced if excess water is first removed from the sludge fed to the system.

For this reason, sludge thickeners as described in an earlier portion of this chapter are often used in order to thicken the sludge prior to its discharge to the digestion system. Figure 6-8 has previously shown in graphical form the tremendous effect that thickening sludge prior to discharge to digesters can have in reducing required digester volume. In plants where sludge thickening devices are not provided, operators should strive to withdraw as thick a sludge as possible from sedimentation basins to minimize the amount of excess water pumped to the digesters.

Since optimum digestion occurs at temperatures of from 90 to 98 degrees Fahrenheit, it is necessary in most climates to heat the sludge feed. Heating of the sludge may be accomplished either by providing heat exchangers external to or inside of the digester. Since it is necessary to heat in order to maintain optimum digestion temperature, it can be seen that if a thin sludge is fed to the system, that large unnecessary volumes of water must also be heated. Accordingly, the feeding of a thin sludge not only occupies needless volume in a digestion system but also requires additional heat energy which could otherwise be saved.

(4) classification. Anaerobic sludge digestion systems may be classified according to the number of tanks employed as either single stage or multiple stage.

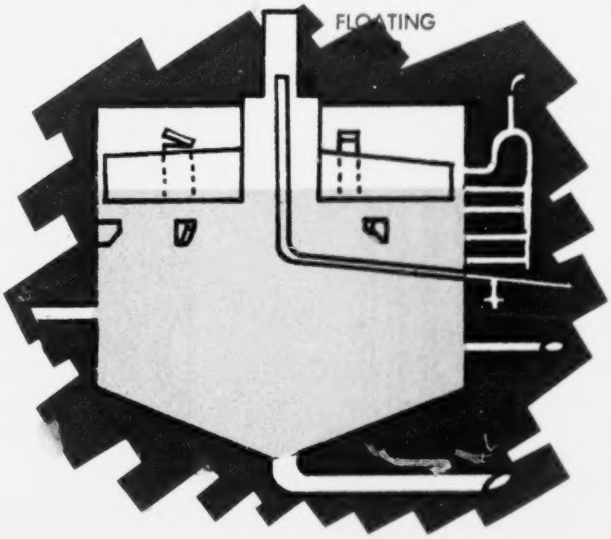
In the single stage system, all of the sludge digestion processes must be carried on in a single tank. The digestion of the sludge creates some natural circulation as the gases produced rise through the sludge mass. However, the circulation caused by the gas is insufficient to provide the necessary mixing action required for optimum digestion. If artificial circulation is not provided, the digestion process may be retarded. In a single tank, however, such circulation interferes with liquid-solid separation as well as the compaction of the digested solids. This may result in a supernatant very high in solids content which when returned to the treatment plant for additional treatment may cause upsets. Furthermore a very thin digested sludge which has a high water content and accordingly is much more difficult to dry or dispose of.

Except in very small installations, multiple sludge digesters are usually provided and operated as multiple stage digesters. With two or more tanks connected in series the initial stages of digestion are accomplished in the first digester or set of digesters with transfer to the second set of digesters occurring essentially at the same rate as the feed rate of raw solids to the first digester. In the first digester, good mixing and rapid gas production may be accomplished. In the second tank a relatively quiet environment is established by reduced gas production and limited circulation. Here separation and compaction may occur naturally without the interferences caused by a high degree of mixing.

(5) equipment. Equipment used in the anaerobic digestion of sludge includes digester tanks, tank covers (either fixed or floating), gasholders, pumps, heat exchangers and mixers.

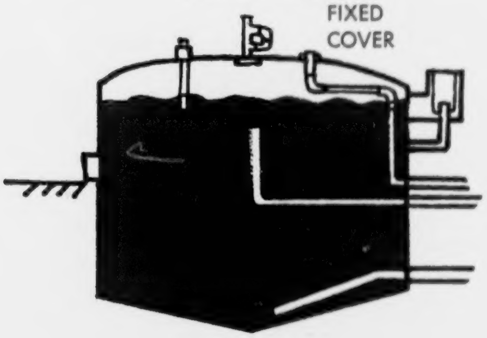
Digester tanks are usually circular, reinforced concrete tanks, 20 feet or more in depth. They may be almost entirely above ground or more commonly, partially buried. Some digesters are left open at the top (uncovered); however, this practice is not common. Digesters are usually insulated for the portion of tank which extends above ground. The use of brick veneer is common as it both insulates and provides good appearance. Digester covers may be either fixed (immovable) or floating (movable). Fixed covers are generally constructed of reinforced concrete although steel is sometimes employed.

Floating covers may be of two types—those which "float" on the liquid surface are generally termed floating covers; those which "float" on a gas surface due to gas pressure are generally termed gasholder covers. Floating covers of either type have the advantage of making possible digester operation at various depths of liquid; whereas, with fixed covers this is usually not possible. Figures



SLUDGE DIGESTER

Figure (6-35)



SLUDGE DIGESTER

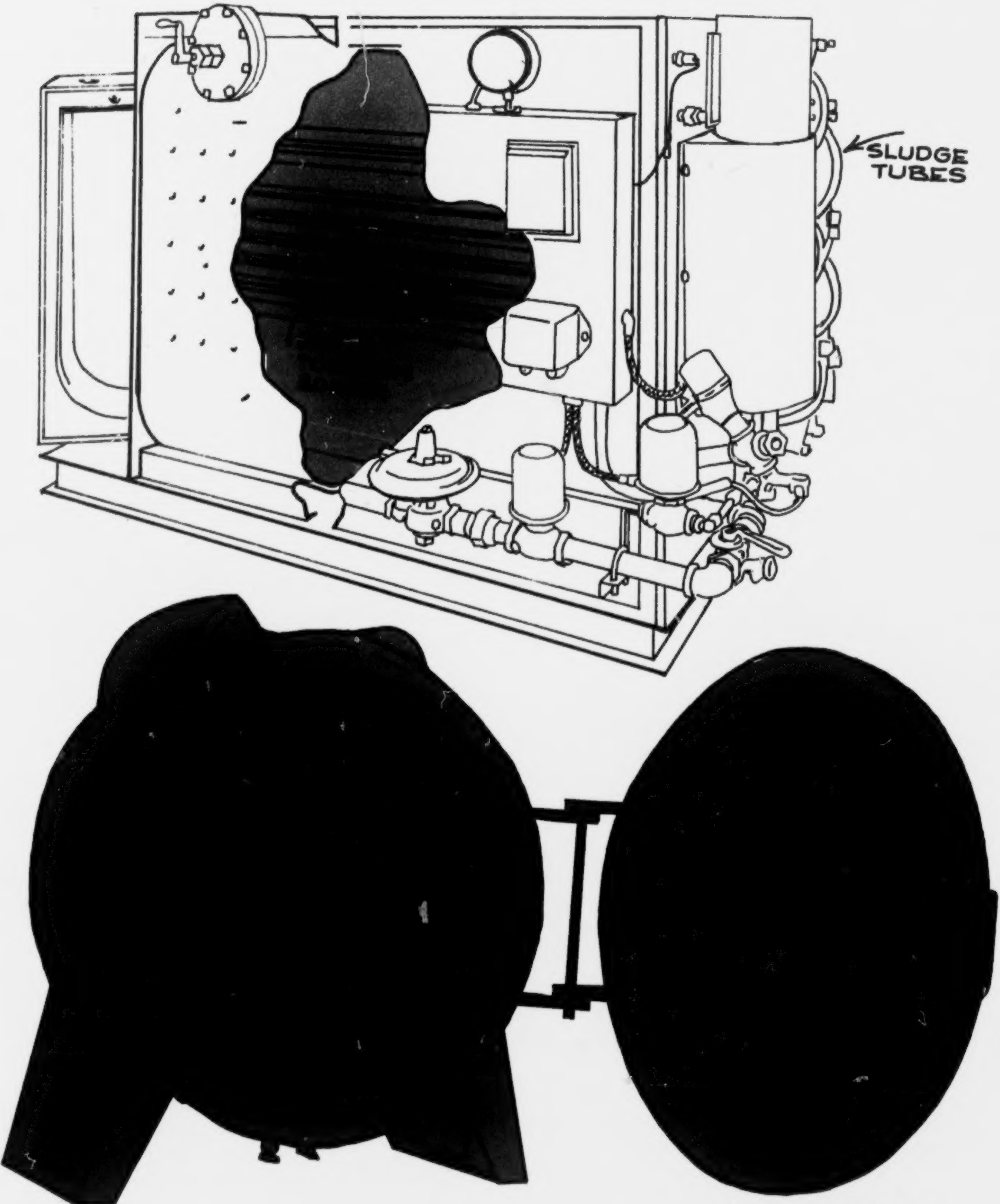
Figure (6-36)

6-35 and 6-36 illustrate typical floating covers. Where floating covers are employed, care must be taken to ensure that scum build-up around the cover skirt does not become so thick as to impede the cover-travel since the cover must be free to travel up and down with the liquid surface. If floating covers are allowed to bind or stick in place, serious structural damage may result if the liquid surface rises or falls. Gasholder covers are similar to floating covers as described above excepting that much deeper side skirts are employed and the covers are designed to "float" on a cushion of gas rather than liquid. Gasholder covers have the capability to store considerable volumes of digester gas for use at a later time when gas production may occur at a lesser rate than does gas consumption. While providing some minimum gas storage capability, fixed covers and ordinary floating covers do not have this particular capability.

Recirculation and mixing within primary digesters is often accomplished by the use of pumps. Commonly used types of pumping equipment include both non-clog cetrifugal pumps and the recessed impeller type of centrifugal pump such as manufactured by Wemco. Positive displacement pumps are rarely used because of the need for continuous operation.

Heat exchangers for digester heating may be either internal or external to the digester. Various types of heat exchangers of either type are available from many different manufacturers. Of the external type heat exchangers, the most common are the sludge tube type and the spiral flow type. The sludge tube type consists of a compact series of pipes which are inserted through a steel chamber. Hot water circulates in the chamber and surrounds the sludge pipes. Sludge is pumped through the pipes and is heated by the transfer of heat from the hot water through the pipe wall to the sludge. Normal maximum hot water temperature is approximately 160 to 170 degrees Fahrenheit. Spiral flow heat exchangers operate in a similar manner but are constructed of two concentric hollow spirals contained in a steel chamber. Hot water circulates in one spiral and sludge in the other. Figure 6-37 illustrates two types of external heat exchangers. Internal heat exchangers may take many forms; however, basically most consist of metal pipes or hollow steel or wrought iron sections, immersed in the digester contents through which hot water is circulated. The major disadvantage of internal heat exchangers is the necessity for complete shutdown and draining of the digester in order to clean or repair heat exchanger components. For this reason, care must be taken to limit hot water temperatures so as to minimize the caking of sludge on heat exchanger surfaces. Maximum hot water temperatures for this type of heat exchanger seldom exceed 150 degrees Fahrenheit and often lower where pipe coils are used. Since boilers operate inefficiently at these temperature ranges, hotter boiler water is usually tempered by mixing with cooled water returning from the digester heat exchanger using a three-way temperature controlled valve to effect the blending.

Digesters may also be heated by direct steam injection usually at the bottom of the digester or in


SLUDGE TUBES

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Co. Inc.

Figure (6-37)
Typical External Digester Heat Exchanges

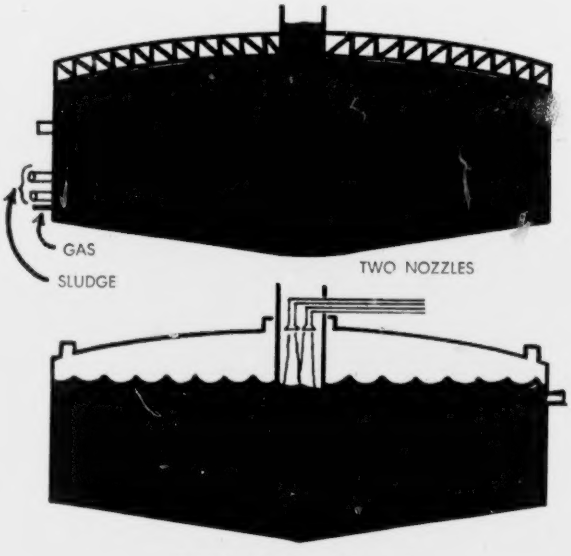
the incoming raw sludge line. Direct steam injection has the disadvantages of requiring a continuous supply of fresh boiler feedwater as well as the dilution of digester contents with unnecessary amounts of water from the condensed steam.

In a few instances, digesters have been heated by the firing of gas or oil in fire tubes or special combustion chambers located inside the digester.

Digester mixing may be accomplished by mixers suspended in the tank contents, by the action of recirculation pumps or by gas mixers. Mechanical mixers consisting of rotating propellers suspended inside a draft tube are quite common and function very satisfactorily. The draft tube is often made up as a hollow section through which hot water circulates, thus both mixing and heat exchange may be simultaneously accomplished. This type of mixer has a disadvantage in that power requirements are relatively high. Where circulating pumps are used, it is common practice to pump liquid from near the bottom and return the recirculated liquid near the digester top. This serves to break up scum formations as well as mix the digester contents. Often the recirculated sludge is also passed through an external heat exchanger by the pump so as to achieve both the functions of mixing and heating simultaneously. Digester mixing by gas recirculation is becoming more prevalent and is widely used in both new plants and in the remodeling of existing digesters. Basically, the process consists of compressing digester gas taken from the digester and releasing the compressed gas near the digester bottom, Figure 6-38. The mixing action thus obtained is similar to that described previously under the mixing of activated sludge basins. Several proprietary gas mixing systems are now in use. Some are operated continuously while others are designed to operate on a cyclical basis. Figure 6-39 illustrates a typical craft-tube type of digester mixing system.

E. Aerobic Sludge Digestion.

(1) purpose. The purposes of aerobic sludge digestion are the same as those previously discussed for anaerobic sludge digestion, with the exception that the by-products of aerobic sludge digestion cannot be utilized to minimize overall cost of operation.


GAS
SLUDGE
TWO NOZZLES

SLUDGE DIGESTION GASMIXING

Figure (6-38)

Typical Gas Mixer for Sludge Digester

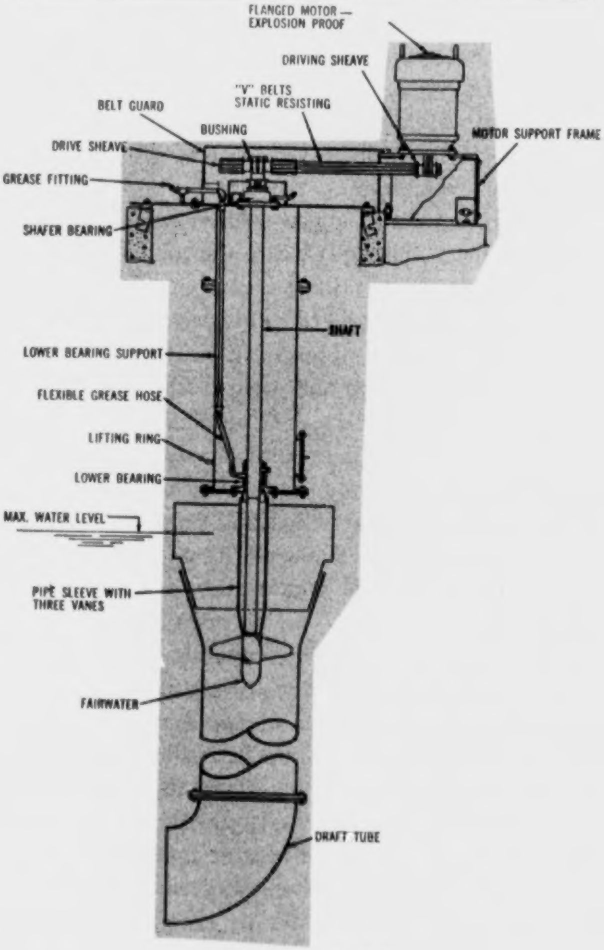

FLANGED MOTOR — EXPLOSION PROOF
DRIVING SHEAVE
"V" BELTS STATIC RESISTING
BELT GUARD
BUSHING
MOTOR SUPPORT FRAME
DRIVE SHEAVE
GREASE FITTING
SHAFER BEARING
SHAFT
LOWER BEARING SUPPORT
FLEXIBLE GREASE HOSE
LIFTING RING
LOWER BEARING
MAX. WATER LEVEL
PIPE SLEEVE WITH THREE VANES
FAIRWATER
DRAFT TUBE

Figure (6-39)

Typical Mechanical Mixer for Sludge Digester

(2) theory. Aerobic digestion in its simplest form may be defined as the destruction of biologically degradable materials in the presence of free oxygen by aerobic organisms. In this respect, it is essentially the same process which occurs in the activated sludge secondary treatment processes previously described. It is based on the principle that aerobic biological cells will utilize their own cellular material as well as various other organic materials such as are found in sludge as a source of food if there is no other available source of nutrients in their environment. At present, the aerobic digestion process is normally only utilized for the digestion of secondary sludge such as waste activated sludge or trickling filter humus. However, there is no reason why the process cannot be used for a mixture of both primary and secondary sludges. The primary difference between the aerobic and the anaerobic digestion processes is that aerobic digestion requires dissolved oxygen to be present, whereas, anaerobic digestion requires the complete absence of oxygen.

The basic biological process which occurs in aerobic sludge digestion may be described by the following basic equation:

Organic Matter + Oxygen + Ammonia + Aerobic Organisms = Sludge Cells + Carbon Dioxide + Water + Nitrates + Inert Solids.

As previously described, whenever aerobic biological organisms are placed in an environment containing sufficient food and oxygen, the aerobic organisms tend to increase their numbers by forming new active cells until a point is reached wherein there is insufficient food available to keep all of the cells thus formed alive. When this point is reached, the remaining active living cells enter an endogenous metabolism phase as previously described; and the growth of new cells, for all practical purposes, ceases. When this occurs, the remaining living active cells begin to utilize portions of their own cellular material as a source of food and energy requirements. This, of course, results in the destruction of volatile materials by means of aerobic processes. Since the main purpose of any digestion process is the destruction of volatile organic materials, it can be seen that regardless of whether the destruction process is one of an aerobic or anaerobic nature, the end result is the same, that is, the destruction of volatile organic matter.

(3) pretreatment. Since the aerobic digestion process is relatively new, it has as yet been utilized only to a limited extent. Present uses for the system are limited, for the most part, to the digestion of secondary sludges such as are obtained from extended aeration type activated sludge plants. Since there is no practical reason why other secondary sludges such as those obtained from trickling filter type plants, or for that matter, primary sludges, could not also be digested aerobically, it is to be expected that future uses for the system will include digestion of all types of sludge. At present no particular pretreatment is required when the system is operating on waste activated sludges because the action of the activated sludge secondary treatment units produce a sludge which is easily handled in aerobic digestion systems. It is to be expected as future uses increase, that pretreatment of at least raw sludges may be required prior to their introduction into aerobic digestion systems.

(4) equipment. Basically the only equipment required for aerobic digestion systems would be a source of dissolved oxygen such as might be supplied either by mechanical aerators as previously discussed or by diffused air systems; a basin or tank in which to contain the sludge and equipment for the necessary mixing of the basin contents.

Aerobic digestion equipment is typically included as a part of many extended aeration type package activated sludge plants. In these units the basin generally consists of a steel chamber constructed as a part of the other steel equipment usually provided. In some instances, lined or unlined earthen basins have been used in larger plants. These basins may be either, as required by the particular type of soil conditions encountered in the construction of the basin.

Typically the supply of dissolved oxygen and the necessary mixing action are accomplished by the same equipment whether the equipment is the surface aerator type or the diffused air type. In the case of aerobic digestion, it appears that aeration equipment which is capable of satisfying the necessary mixing requirements will usually have an excess of capacity for providing required oxygen.

RECEIVING STREAM

1. **Purpose.** There exists a tendency for many operators of waste treatment facilities to consider that receiving streams or waterways exist for the purpose of providing dilution and final disposal of treated effluent from their treatment works. This is entirely incorrect. Receiving waterways and, in fact

all waters, exist for a multiplicity of purposes, probably the least important of which is to accept final effluent from treatment works. Some of the purposes of streams and waterways which are of more paramount importance are as follows: water supplies (domestic, industrial, and agricultural); wild life habitat; general recreation and aesthetic enjoyment (picnicking, hiking, fishing, swimming, skiing, and boating); general marine recreation and navigation; fish and shellfish reproduction, rearing and harvest; commerce and navigation; industrial cooling water supplies; hydroelectric power generation; and fish passage.

If waterways existed only for the purpose of diluting and disposing of treated effluents, there would be very little need to regulate water quality other than for purposes of protection of public health. Because there is such a multiplicity of uses for all of our waters, and because most of these uses demand reasonably high quality waters, it has become necessary to formulate and establish water quality criteria, all of which are based essentially on the highest and best use of all of our waterways. This in turn demands that receiving waterways not be significantly degrated by the discharge of treated effluents.

In order to help safeguard overall water quality, the Washington State Department of Ecology has adopted a number of rules and regulations for the operation of public sewage and industrial waste works. Two of these regulations which deal directly with receiving waterways are discussed below. Operators should be aware not only of these regulations but of the several others as well. No treatment plant operator should be without a copy of the rules and regulations for the operation of public sewage and industrial waste works as published by the Washington State Department of Ecology. The intent of all of the various rules and regulations is fairly well summarized by the following two excerpts taken from the above mentioned rules and regulations:

> "**Efficient Operation.** All sewage treatment plants shall be operated at their highest practical efficiency at all times. If after investigation by the Department of Ecology, it is determined that any sewage treatment works is, because of defective design, inadequacy, incompetent supervision, or inefficient operation, causing unsatisfactory conditions in the waters into which the effluent is discharged or otherwise interfering with the legitimate uses of such waters, or causes a menace to public health, the owner shall make such changes in the plant or its operation as are necessary to produce satisfactory results. These changes shall be made within such time limits as are set by the Commission."
>
> "**Bypassing.** Approval shall be obtained from the Department of Ecology for bypassing a sewage treatment plant or any unit thereof except in the case of emergency. If an emergency occurs in bypassing for more than 24 hours, the Department shall be informed immediately."

2. **Water Quality Standards.** In mid-1967 the following four water quality classifications were adopted by the Department of Ecology. Every operator at every waste treatment facility should be aware of these standards and in addition should know which of the four classifications applies to the receiving waterway into which his effluent is discharged.

CLASS AA – EXTRAORDINARY

General Characteristic

Water quality of this class markedly and uniformly exceeds the requirements for all or substantially all uses.

Characteristic Uses

Characteristic uses include, but are not limited to, the following:

Water supply (domestic, industrial, agricultural);

Wildlife habitat, stock watering;

General recreation and aesthetic enjoyment (picnicking, hiking, fishing, swimming, skiing and boating);

General marine recreation and navigation;

Fish and shellfish reproduction, rearing and harvest.

Water Quality Standards

Total Coliform Organisms shall not exceed median values of 50 (FRESH WATER) or 70 (MARINE WATER) with less than 10% of samples exceeding 230 when associated with any fecal source.

Dissolved Oxygen shall exceed 9.5 mg/l (FRESH WATER) or 7.0 mg/l (MARINE WATER).

Temperature No measureable increases shall be permitted within the waters designated which result in water temperatures exceeding 60°F (FRESH WATER) or 55°F (MARINE WATER) nor shall the cumulative total of all such increases arising from nonnatural causes be permitted in excess of t= 75/ (T–22) (FRESH WATER) or t= 24/(T–39) (MARINE WATER); for purposes hereof "t" represents the permissive increase and "T" represents the resulting water temperature.

pH shall be within the range of 6.5 to 8.5 (FRESH WATER) or 7.8 to 8.5 (MARINE WATER) with an induced variation of less than 0.1 units.

Turbidity shall not exceed 5 JTU.

Toxic, Radioactive or Deleterious Material Concentrations shall be less than those which may affect public health, the natural aquatic environment, or the desirability of the water for any usage.

Aesthetic Values shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch or taste.

CLASS A – EXCELLENT

General Characteristic

Water quality of this class exceeds or meets the requirements for all or substantially all uses.

Characteristic Uses

Characteristic uses include, but are not limited to, the following:

Water supply (domestic, industrial, agricultural);

Wildlife habitat, stock watering;

General recreation and aesthetic enjoyment (picnicking, hiking, fishing, swimming, skiing and boating);

Commerce and navigation;

Fish and shellfish reproduction, rearing and harvest.

Water Quality Standards

Total Coliform Organisms shall not exceed median values of 240 (FRESH WATER) with less than 20% of samples exceeding 1,000 when associated with any fecal source or 70 (MARINE WATER) with less than 10% of samples exceeding 230 when associated with any fecal source.

Dissolved Oxygen shall exceed 8.0 mg/l (FRESH WATER) or 6.0 mg/l (MARINE WATER).

Temperature No measureable increases shall be permitted within the waters designated which result in water temperatures exceeding 65°F (FRESH WATER) or 61°F (MARINE WATER) nor shall the cumulative total of all such increases arising from nonnatural causes be permitted in excess of t= 90/ (T–19) (FRESH WATER) or t= 40/ (T–35) (MARINE WATER); for purposes hereof "t" represents the permissive increase and "T" represents the resulting water temperature.

pH shall be within the range of 6.5 to 8.5 (FRESH WATER) or 7.8 to 8.5 (MARINE WATER) with an induced variation of less than 0.25 units.

Turbidity shall not exceed 5 JTU over natural conditions.

Toxic, Radioactive or Deleterious Material Concentrations shall be below those of public health significance, or which may cause acute or chronic toxic conditions to the aquatic biota, or which may adversely affect any water use.

Aesthetic Values shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch or taste.

CLASS B – GOOD

General Characteristic

Water quality of this class exceeds or meets the requirements for most uses.

Characteristic Uses

Characteristic uses include, but are not limited to, the following:

General recreation and aesthetic enjoyment (fishing, swimming, skiing and boating);

Fishery and wildlife habitat;

Industrial and agricultural water supply;

Stock watering;

Commerce and navigation;

Shellfish reproduction and rearing, and crustacea (crabs, shrimp, etc.) harvest.

Water Quality Standards

Total Coliform Organisms shall not exceed median values of 1,000 with less than 20% of samples exceeding 2,400 when associated with any fecal source.

Dissolved Oxygen shall exceed 6.5 mg/l (FRESH WATER) or 5.0 mg/l (MARINE WATER), or 70% saturation whichever is greater.

Temperature No measureable increases shall be permitted within the waters designated which result in water temperatures exceeding 70°F (FRESH WATER) or 66°F (MARINE WATER) nor shall the cumulative total of all such increases arising from nonnatural causes be permitted in excess of $t = 110/(T-15)$ (FRESH WATER) or $t = 52/(T-32)$ (MARINE WATER); for purposes hereof "t" represents the permissive increase and "T" represents the resulting water temperature.

pH shall be within the range of 6.5 to 8.5 (FRESH WATER) or 7.8 to 8.5 (MARINE WATER) with an induced variation of less than 0.5 units.

Turbidity shall not exceed 10 JTU over natural conditions.

Toxic, Radioactive or Deleterious Material Concentrations shall be below those which adversely affect public health during the exercise of characteristic usages, or which may cause acute or chronic toxic conditions to the aquatic biota, or which may aversely affect characteristic water uses.

Aesthetic Values shall not be reduced by dissolved, suspended, floating or submerged matter, not attributable to natural causes, so as to affect water usage or taint the flesh of edible species.

CLASS C – FAIR

General Characteristic

Water quality of this class exceeds or meets the requirements of selected and essential uses.

Characteristic Uses

Characteristic uses include, but are not limited to, the following:

Commerce and navigation
Cooling water
Boating
Fish passage

Water Quality Standards

Total Coliform Organisms shall not exceed median values of 1,000 when associated with any fecal source.

Dissolved Oxygen shall exceed 5.0 mg/l (FRESH WATER) or 4.0 mg/l (MARINE WATER), or 50% saturation whichever is greater.

Temperature No measureable increases shall be permitted within the waters designated which result in water temperatures exceeding 75°F (FRESH WATER) or 72°F (MARINE WATER) nor shall the cumulative total of all such increases arising from nonnatural causes be permitted in excess of $t = 125/(T-12)$ (FRESH WATER) or $t = 64/(T-29)$ (MARINE WATER); for purposes hereof "t" represents the permissive increase and "T" represents the resulting water temperature.

pH shall be within the range of 6.0 to 9.0 (FRESH WATER) or 7.0 to 9.0 (MARINE WATER) with an induced variation of less than 0.5 units.

Turbidity shall not exceed 10 JTU over natural conditions.

Toxic, Radioactive or Deleterious Material Concentrations shall be below those which adversely affect public health during the exercise of characteristic usages, or which may cause acute or chronic toxic conditions to the aquatic biota, or which may adversely affect characteristic water uses.

Aesthetic Values shall not be interfered with by the presence of obnoxious wastes, slimes, or aquatic growths or by materials which will taint the flesh of edible species.

3. **Degradation of Streams.** Every body of water constantly undergoes a constant aging process which is termed eutrophication. This aging process is essentially an irreversible process which naturally occurs in all waters through the accumulation of essential nutrients such as phosphates and nitrates. The natural aging of streams is a very slow process and may take centuries to significantly change the appearance of a stream or lake. Unfortunately the rate at which this natural aging occurs is tremendously increased by nearly all of man's activities. Mechanisms by which aging or degradation of streams and lakes occurs are discussed as follows:

A. Natural Mechanisms. Because of the rather universal properties of water as a solvent, waters which flow either over or through the ground have a natural tendency to dissolve and take into solution naturally-occurring minerals. Many of these minerals contain specific chemical compounds which play a role in the natural fertilization and hence the aging of streams and lakes. In addition, the flowing water tends to accumulate and hydraulically move sediments from areas of high velocity and deposit these sediments in areas of low velocity.

B. Man-Made Mechanisms. Man-made mechanisms are responsible for the rapid degradation of many of our streams and lakes to an immensely larger degree than are naturally-occurring causes. Some of the mechanisms by which man-made pollution enters bodies of water are as follows:

(1) agricultural processes. As the use of both organic and inorganic fertilizers increases by the agricultural industry, more and more nutrient material such as nitrogen and phosphorus enter receiving waterways by the simple mechanism of surface water runoff into the streams.

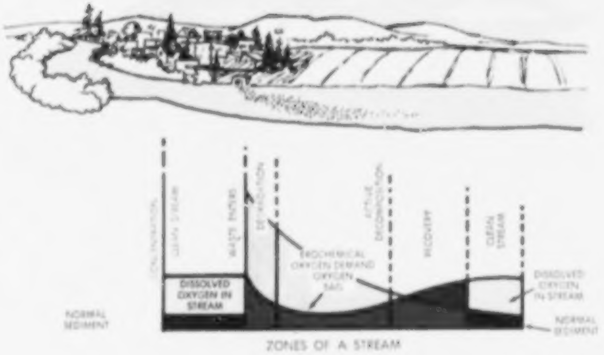
(2) industrial processes. Nearly all industrial processes result in the creation of either liquid or solid wastes. Liquid wastes are usually discharged to receiving streams or to municipal sewerage systems and often contain large amounts of nutrients, which if not removed can accelerate the aging process of streams. Solid wastes if not disposed of properly, often release nutrients into surface or groundwater because of the natural solvent power of water which comes into contact with the solid wastes. Thus, the nutrients from solid wastes may find their way into waterways in a manner similar to that which occurs with fertilizers spread on agricultural land.

(3) domestic and industrial waste treatment plants. Effluents from all treatment works contain nutrients to a more or less degree depending on the efficiency and type of treatment provided. These nutrients almost always find their way into a receiving waterway thus increasing the rate at which aging in our streams occurs.

C. Effects of Stream Pollution or Aging. The effects of stream pollution might be summed up rather completely by the following short statement. A LITTLE POLLUTION IS BAD: MORE IS WORSE. Pollutants which once enter a stream tend to trigger a chain reaction which is essentially irreversible. All pollution ages every receiving waterway it enters and the process once begun is almost impossible to stop. When pollution enters a waterway even in small concentrations the immediate effect is to stimulate or increase productivity within the receiving waterway. An example of an easily visible nature is the increase of algae which occurs in streams which receive even well-treated effluents. The growth of this algae in turn stimulates growth of other organisms by providing a food supply for other small forms of aquatic life. This growth in turn stimulates the growth of fish and crustacea populations. Thus the stream or lake would support an ever-increasing amount of aquatic life. Up to a certain point this is not in itself harmful; however unless properly managed the process tends to continue until at some point a breakdown occurs usually because of lack of dissolved oxygen or because of failure of some specific link in the whole chain of events. When breakdown occurs the resulting mass death of nearly all species of all the higher aquatic life results in the creation of oxygen-void or anaerobic conditions. This then gives rise to very offensive odors and stimulates the growth of undesirable organisms which are able to live in environments void of oxygen.

Even if complete breakdown does not occur in very productive streams, the natural life and death of all of the various aquatic life tends to create bottom sediments which increase very rapidly in polluted streams. By the action of anaerobic bottom living organisms, nutrients which are contained in sediments which settle to the bottom are continually released from the sediments and made again available for reuse by other forms of aquatic life. This results in a continuous recycle of nutrients within a receiving waterway and explains to a large extent the almost irreversible nature of the aging process.

4. **Phases of Biological Stream Recovery.** For the purposes of illustration the following section is included to describe what happens to a stream which receives a source of pollution (organic matter) illustrated in Figure 6-40. For the purposes of this illustration, it is assumed that the pollution is introduced into what would be an otherwise unpolluted stream. It is further assumed that the amount of pollution which is introduced into a stream is far in excess of the stream's natural ability to immediately recover. There are four major phases through which any receiving waterway goes from the time it is first polluted until the time it returns to a semblance of its original condition. These four phases



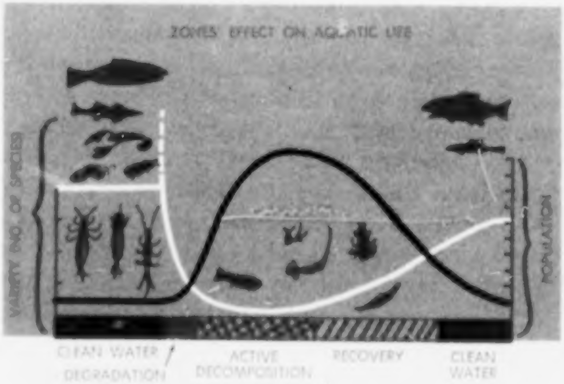
Zone of Degradation and Recovery

Figure (6-40)

are not clearly divided, one phase from another, but rather tend to blend one phase into another. It would be difficult to visually ascertain in any given stream exactly where one phase begins and another ends. However, for the purposes of illustration, the phases are defined as though they were clearly discernible. These four phases are as follows:

A. Zone of Degradation. This is the phase which occurs in a stream which has very recently been subjected to a massive concentration of pollution or a stream which receives a continuous source of pollution in excess of its natural recovery powers. The physical characteristics of the zone of degradation are as follows: (1) Dissolved oxygen content is less than saturation and falls rapidly, (2) fish life decreases drastically, (3) turbidity increases, (4) algae decreases, (5) fungi are present in small quantities but increasing, (6) bacteria are present in large numbers and increasing.

B. Zone of Active Decomposition. In this zone the decomposition of pollution is proceeding at its maximum rate. The characteristics of this zone include (1) dissolved oxygen drastically depleted and very often no dissolved oxygen is found, (2) no fish life may be found, (3) turbidity very high, (4) algae not present, (5) fungi may be absent if complete lack of dissolved oxygen exists or may be present in large amounts if very low dissolved oxygen concentrations exist. If present, fungi usually tend to accumulate in masses of stringy material, usually light gray or pinkish in color, (6) floating sludge and scum are usually observed, (7) gas bubbles may be seen arising from bottom sludge accumulations and the odor is primarily sulfurous in nature, and (8) very large concentrations of bacteria are present.



Zone of Degradation and Recovery

Figure (6-41)

C. Zone of Recovery. In this zone the greatest part of the polluting material has either been removed or made inert. The stream is starting to simulate a more normal appearance. The zone is indicated by the following characteristics: (1) dissolved oxygen is below saturation but is increasing, (2) fish life appears; usually the first fish to be noticed in such a zone are rough fish such as carp and catfish, (3) turbidity is decreasing, (4) algae and larger plants begin to appear, (5) fungi are present only to a limited degree, and (6) bacteria are fewer in number with no particular species predominating illustrated in Figure 6-41.

D. Zone of Cleaner Water. This zone is characterized by the return of the stream to its normal condition (that is that which existed prior to its pollution), except for increases in solids content in the stream bed. This condition exists when (1) the dissolved oxygen is close to saturation, (2) fish life regains its balance; number of fish species increases but total fish weight per acre foot of water is less than in the zone of recovery, (3) algae may have bloomed resulting in a pH increase, (4) bacteria are present in normal concentrations.

CHAPTER VII

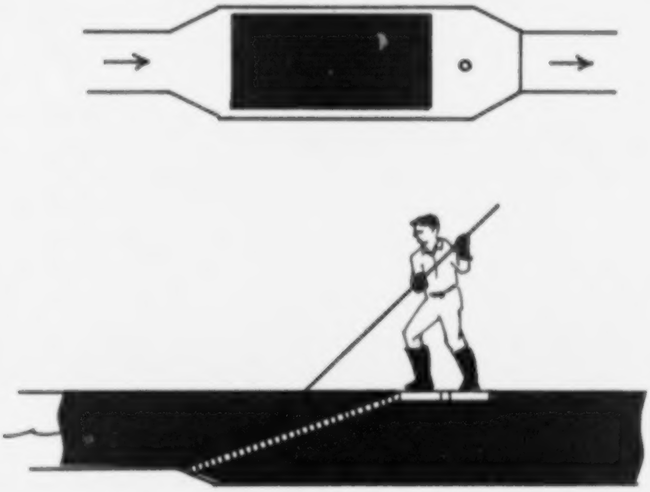
TREATMENT PLANT OPERATION

OPERATION OF TREATMENT AND DISPOSAL COMPONENTS

1. **Mechanical or Physical Treatment Units.**

A. Coarse Bar Racks and Bar Screens.

(1) coarse bar racks. Daily removal of the debris collected on coarse bar racks normally is sufficient during dry weather flows. During periods of the year when large volumes of storm water enter the sewerage system, more frequent cleaning of coarse racks may be required in order to prevent flows from backing up the incoming sewer. Material removed from coarse bar racks often may be hosed off thoroughly and hauled to a disposal site for municipal rubbish. In cases where the majority of materials caught on coarse bar racks is wood or other combustible items it may be possible to burn this material at the plant site. Operators should always check to make certain that burning of such items will not violate local ordinances or regulations with respect to burning and air pollution.

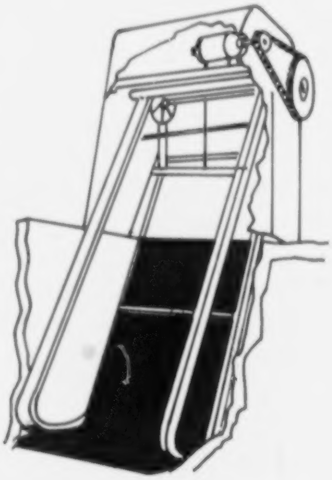


BAR SCREEN HAND RAKED

Figure (7-1)

(2) manually cleaned bar screens. Screenings should be removed as often as is necessary to prevent interference with reasonably free flow to the sewer; this may be from 2 to 5 times daily. Screenings thus removed should be raked to the draining slab such as is provided at the plant or if none is provided, should be placed in covered barrels. Often the barrels used are 55-gallon oil drums, and many operators have found it convenient to perforate the bottom and the sides of the barrels in order to promote the draining of liquid from the screenings. Screenings thus collected should be buried or incinerated daily. Screenings should not be allowed to accumulate for any extended period of time because often they will begin to decompose fairly quickly, especially during hot weather. This gives rise to offensive odors and also attracts rodents and flies.

B. Mechanically Cleaned Bar Screens. Mechanically cleaned bar screens are usually operated on an automatic basis, controlled either by flow sensing devices or by a time clock. If mechanical bar screens are not provided with automatic operating controls, they should be operated frequently enough to keep the channel or sewer flowing freely. Mechanisms, chains, sprockets and all other moving parts require lubrication and adjustment as recommended by the manufacturer. Screenings removed from the flow by these devices are usually ground and returned to the sewage flow. If a grinder is provided it should be operated as is required to keep pace with the rate at which solids are collected. Large, difficult-to-grind items which may be caught on the screens should be removed prior to the introduction of the screenings into the grinder in order to prolong the grinder's life and to avoid possible equipment failure or dangerous operation. If screenings are not to be ground, they should be disposed of regularly in a manner as recommended for screenings removed from manually cleaned bar screens.



MECHANICALLY CLEANED SCREEN

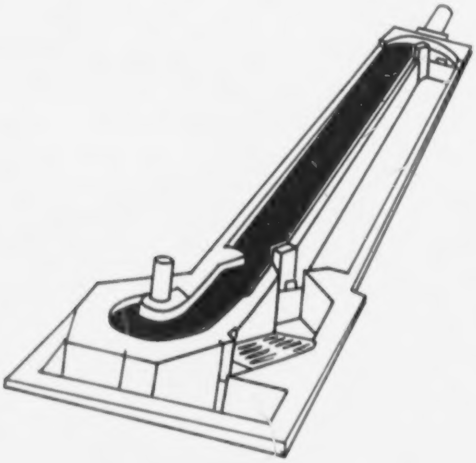
Figure (7-2)

C. Skimmers. Operation of skimming devices is discussed in the section on sedimentation basins.

D. Grit Removal Units.

(1) velocity control units. Hand cleaned grit chambers operating by the control of waste velocity are commonly used in small treatment plants.

Where hand cleaned units are provided, they usually consist of two parallel elongated channels equipped with velocity control devices to provide a nearly constant velocity of about one foot per second for the expected range of flow rates. Under ideal operating conditions and if a sufficient number of channels are provided, effective grit removal can be accomplished while one or more additional channels are idle for dewatering and grit removal.



GRIT CHAMBER HAND CLEANED GRAVITY TYPE

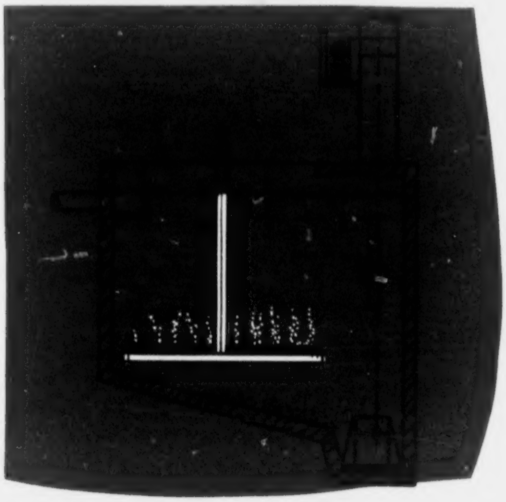
Figure (7-3)

Operation of this type of grit removal equipment then consists of measuring and locating the depth of grit in the channels and, after grit has accumulated to about one-half the liquid depth in any given channel, or about two-thirds of its length, taking that particular channel out of operation for cleaning while bypassing the waste flow to the unused channel which has been previously cleaned. The channel to be cleaned is then dewatered by opening valves on the dewatering line. The flow of water thus released is usually returned to the headworks of the plant for complete retreatment. After the channel has been dewatered the grit is removed using shovels or shoveling hoes especially designed to fit the shape of the channel. Grit thus removed may be buried in shallow trenches or hauled to a sanitary land fill. After the grit has been removed from the channel, it is normal practice to flush out the channel and drain lines as well as to hose down the sidewalls before closing the valves on the drains. The channel is then ready to receive flow at such time as it may be needed. It is advisable to analyze the grit being removed from grit channels periodically in order to determine whether or not large amounts of organic matter are being caught with the grit or whether or not only large particles of grit are being collected. If considerable amounts of organics are found in the settled grit, the probable cause is much too slow a velocity in the grit channel; and if only large particles of grit are being collected, the probable cause is too fast a velocity. In either case, the situation can be remedied by adjusting the velocity control device in order to create a desired velocity of approximately one foot per second. Where Parshall flumes or proportional weirs are used as a velocity control device, it may be necessary to have new proportional weirs built or to enlarge or decrease the float of the Parshall flume, depending upon the velocity conditions which actually exist. Unless an operator is well versed in hydraulics, he should always seek out engineering assistance before attempting to change the configuration of velocity control devices provided.

Mechanically cleaned, velocity controlled grit removal units are essentially constructed the same as the nonmechanically cleaned units with the exception that mechanical scrapers are included as a part of the design. These mechanical scrapers automatically drag the grit to a hopper usually located at the influent end. The grit is them discharged to trucks for removal usually by means of screw conveyors or reciprocating rake type conveyors. The mechanical equipment associated with this type of grit chamber is generally automatically controlled by means of a time clock. The mechanism should be operated to ensure removal of all grit that settles in the channel. The sprockets, chains, and flights should be maintained in accordance with manufacturer's instructions; and in addition, all moving equipment should be kept free of debris. Daily hose down of all exposed walls and equipment may be necessary. At least once a year each mechanically equipped unit should be completely dewatered and inspected. Repairs and adjustments should be made in order to ensure that the equipment will function properly without unscheduled shutdowns. If possible, the equipment should be taken out of service for inspection and repairs during times of the year when the least amount of grit is normally received at the plant. In this manner, succeeding processes will not be adversely affected.

(2) aerated grit removal tanks. Because they contain essentially no moving parts, aerated grit chambers are extremely easy to operate and maintain. About the only periodic maintenance required is to ensure that the air diffusion devices are kept in a relatively clean condition to allow free passage of compressed air into the grit-containing waste. Air diffusers should be inspected at least on an annual basis and cleaned if necessary. Grit elevators or grit pumps, either of the centrifugal or air lift type, which are provided to remove the accu-

mulated grit from aerated grit chambers should be operated and maintained in strict accordance with the manufacturer's instructions. Particular care must be paid to the lubrication of grit elevators in order to assure long life. Centrifugal pumps, if used to remove grit from the chamber, should be inspected at least four times yearly. Particular attention should be paid to the packing and seals of these units since they are subject to quite rapid wear by reason of the very abrasive material which they must pump. Air lift pumps should be inspected at least twice yearly to assure that grease or scum accumulations have not built up within the pump column. Such accumulations should be removed immediately. Air lines should be fully opened periodically in order to blow free of obstructions which may have accumulated. The air discharge orifices should be inspected routinely to assure good operation.



GRIT CHAMBER MECHANICALLY CLEANED
Figure (7-4)

(3) detritus tanks. Detritus tanks resemble small, mechanically equipped sedimentation basins and are operated in much the same manner. All of the mechanical equipment, including the drive head, scraper plows, solids return pump, screw and reciprocating rake conveyors, etc. should be lubricated and maintained in strict accordance with the manufacturer's instructions. The tanks are normally automatically controlled by means of a time clock; however, in some instances they are designed to run continuously. Detritus tanks should be completely dewatered at least annually at a time when the least amount of grit may be expected in the plant flow. Any necessary preventive maintenance should be done at this time. Particular attention should be paid to submerged metal parts and a regular schedule of painting or other protective coating should be followed. The importance of the use of proper lubricating oils and greases cannot be overstressed, and the manufacturer's instructions should be followed implicitly. Routine daily maintenance should include hose down of all weirs and baffle plates and concrete walls at the water line in order to prevent excessive accumulations of grease and scum. If pumps are used in conjunction with the equipment, packing and seals should be inspected regularly because of the abrasive nature of the material handled.

(4) cyclones. Grit cyclones should be inspected and cleaned daily. Particular attention must be paid to the apex portion of the cyclone since this is an area of restricted flow and experience has shown that it is quite prone to plugging problems. In particular, small items such as bottle caps and razor blades have shown a tendency to plug up cyclones currently in use. Because of the possibility of encountering such sharp objects, the operator should always use particular care and protect his hands with heavy gloves when cleaning the apex. Since cyclones are normally located in locations where they are exposed to weather, a continuing program of application of protective coatings, such as painting, is required. Normally, centrifugal type pumps, or in some cases progressing cavity type pumps such as the Moyno, are used to pump grit-laden liquid to grit cyclones. These pumps must be regularly inspected and particular care must be paid to the seals and packing because of the abrasive nature of the fluid being pumped.

(5) grit classifiers and washers. Sprockets, chains, flights, and gear boxes associated with this equipment should be maintained in strict accordance with the manufacturer's instructions. Daily operation should include hose down of the equipment in order to prevent accumulations of floating grease and scum at the waterline or on moving equipment. Periodic painting of submerged and nonsubmerged ferrous metals is required in order to prevent rust. Lubricants specified by the manufacturer or their equivalent should always be used. Grit classifiers and washers normally operate on a continuous basis and depend for their successful operation on proper liquid flows to the unit. If the flow of liquid to the unit is too great, fine grit particles will be washed from the unit. If the flow is too small, organic materials will not be thoroughly washed from the grit. If either of these two problems occur, it is an indication of improper liquid flow to the unit, and the flow should be adjusted accordingly.

E. Solids Grinders.

(1) separate screenings grinders. Separate screenings grinders are usually operated by means

of manual off-on control. Screenings are collected and held for a period of time prior to grinding in the machine. Screenings to be discharged into such grinders should be relatively free of very large organic solids, and in addition bits of metal should be picked from the material prior to discharge into the grinder. Grinders should be inspected at least four times per year and repairs made as required. The grinders themselves should be maintained in strict accordance with the manufacturer's instructions; and because of the possibility of danger to operating personnel the machines should never be operated unless they are in good condition. Most grinders require a flow of water into the grinding mechanism along with the solids to be ground. Care should be taken not to operate the grinders without first establishing this flow of water.

(2) in-flow grinders (comminutors and barminutors). These devices are usually operated continuously. Stones, sticks, and etc., should be removed from the channel leading to the comminutor or barminutor whenever observed in order to protect the cutting surfaces of the machine. It is advisable to bypass these machines periodically in order to remove any large heavy objects which may have settled before such objects reach the mechanism. As with all mechanical equipment comminutors and barminutors should be lubricated and otherwise maintained in strict accordance with the detailed instructions of the manufacturer. The cutting surfaces of the machines require sharpening and clearance adjustments from time to time. Sharpening and adjustment should also be performed in accordance with the manufacturer's instructions. A regular schedule of painting or other protective coating application for the machines should be followed particularly with respect to machines which are located in locations exposed to the weather.

F. Preaeration Chambers. Operation and maintenance of the aeration chambers is normally quite simple because there usually are no moving parts in the units to cause wear. Routine maintenance should include daily washdown of walls, particularly at the water line in order to remove accumulations of grease and scum. Air diffusion devices should be inspected at least four times yearly and cleaned as required. The entire chamber should be bypassed and completely dewatered at least once per year, and any accumulation of material which has settled to the bottom should be cleaned out at this time. It is advisable to perform the cleaning of such basins during periods when waste received at the plant is normally at its freshest in order to prevent possible upset of sedimentation basins following the preaeration chamber.

G. Sedimentation Basins.

(1) general. No matter what type of sedimentation basin is provided, sedimentation will be most efficient if the flow is distributed equally among all available tanks. Unequal flow causes uneven detention periods in the various tanks and always results in a lesser overall reduction of suspended solids and BOD. Overflow weirs must be kept clean and must be set at equal elevations in order to maintain equal flow. Inlet baffles should be kept clean and in sound condition. Inlet baffles which are partially plugged or broken will always reduce efficiency of sedimentation basins.

(2) mechanically equipped basins. Mechanically equipped tanks and mechanical equipment should be visually inspected several times during each shift. Sludge removal equipment, grease skimmers and pumps should be checked for proper operation and conditions on the sedimentation basin surface should be observed. Floating sludge or an abundance of gas bubbles are evidence of equipment or process breakdown. Often a breakage of underwater chains can be detected in this way. Scum skimming devices should be operated only as is necessary in order to remove floating materials and prevent their exit from the sedimentation basin by passage from the scum baffles and over the effluent weirs. Excessive operation of skimming equipment will result in too much water being carried over with the scum. This practice increases the load placed on digesters or other solids handling equipment. Insufficient skimming allows scum to flow out of the sedimentation basin and impose an undesirable load on secondary treatment units which follow. Ideally, small amounts of scum should be skimmed on a regular cyclical basis rather than larger amounts of scum being skimmed two or three times daily. Routine daily operation and maintenance should include the removal of accumulations from inlet baffles and effluent weirs using a high pressure water hose and a broom if required. Scum removal equipment should be cleaned regularly. This equipment is a major source of obnoxious odors and an unsightly appearance when neglected.

Mechanical equipment associated with this type of sedimentation basin should be maintained and lubricated in strict accordance with manufacturer's instructions. Any reliable oil company usually can provide the services of a trained lubrication engineer to make recommendations as to the proper types of oils and greases to be used if the information originally supplied by the manufacturer is not available. Schedules for lubrications and other routine jobs should be posted on a check chart system so that a record can be kept of the date when lubrication was done and when the lubrication must be repeated.

The underwater portion of mechanically equipped sedimentation tanks should be inspected regularly. Once a year is usually sufficient. The best time for doing this depends on weather, treatment requirements and available personnel. To do this the tank should be dewatered by discharging its contents to another tank whenever possible, and all submerged mechanical equipment should be checked for wear and corrosion. On rectangular tanks with mechanical sludge collectors, the wooden flights, wearing shoes, main chains, drive chains, sprockets, guide rails, and grease skimmers should be checked; and all defective or badly worn parts should be replaced or repaired. Chains should be adjusted and flights should be checked in order to assure that proper clearance of tank walls (at least one inch) is maintained. All metal work should be checked for corrosion and replaced if necessary. Protective coating or paints should be applied as required. The concrete basin walls and floors should be checked as required and the entire tank generally cleaned by hosing. Any objects found in the bottom of the tank such as broken metal or concrete which could possibly cause troubles with sludge pumps, should be carefully removed.

In cases where sedimentation basins are constructured mostly underground, care must be taken when dewatering in order to ensure that the tank is not floated out of the ground by high groundwater conditions. Many tanks are equipped with underdrain systems or with hydrostatic relief valves which will relieve groundwater pressure back into the tank or out of the ground surrounding the tank. Operators should check to make certain that such hydrostatic relief systems are in operation if the tank is to be dewatered during a period when high groundwater is suspected. If such devices are not provided or if they do not function properly, the tank should never be dewatered unless the groundwater table is low enough so as to not cause danger to the structure.

In treatment plants located in areas subject to flooding, it is considered good practice to keep unused basins filled with clean water in order to prevent flotation should a flood or high groundwater conditions occur. Under these conditions care must be taken to assure that the tanks do not provide breeding grounds for mosquitoes or other insects.

In particular, primary sedimentation basins are closely interrelated with secondary treatment processes which follow as described in previous portions of this manual. No other single unit provides as much opportunity for detection of conditions which affect the performance of other plant processes. By early detection of unusual characteristics, the operator frequently may adjust his normal methods of management of primary sedimentation basins so that harmful and deleterious effects on later phases of treatment may be minimized. Some of the symptoms which operators should pay particular attention to are as follows:

a. floating sludge. Whenever floating sludge is observed on the surface of sedimentation basins it is usually an indication that the sludge removal rate is insufficient to remove all of the accumulated solids within the tank. If the tank is mechanically equipped, the scrapers should be operated for longer periods of time or more frequently. If this does not cure the problem, an inspection should be made to determine if the scrapers or plows, in the case of circular tanks, are broken or improperly adjusted. In the case of non-mechanically equipped sedimentation basins, sludge should be removed from the hoppers more completely by pumping or gravity withdrawal for longer periods or at slower rates. Opening of sludge removal valves from hoppers to allow too great a rate of sludge removal often results in water-holing of the sludge blanket and removal of tank liquid rather than accumulated sludge. Where sludge clings to inclined surfaces, in the case of non-mechanically equipped tanks, it may be necessary to scrape these inclined surfaces by means of long-handled brooms or scrapers periodically.

INFREQUENT SLUDGE PUMPING
CAUSES BUILDUP & SEPTICITY
Figure (7-5)

b. basin contents black or odorous. Septic conditions in primary sedimentation basins often are caused by raw wastes arriving at a sewage treatment plant in a septic condition. This is quite often the case when temperatures are warm and when the main sewer leading to the plant is quite long. Actually, the operator has very little control over whether or not sewage is septic when it arrives at the treatment plant; however, if the plant is equipped with preaeration devices, the operator should take care to operate the preaeration devices at their maximum capacity.

Another cause for black and odorous contents in primary basins can sometimes be the discharge of very poor quality supernatant from digesters. If this occurs, operators should attempt to withdraw supernatant of better quality from other depths in the digester or if this is not possible sometimes supernatant can be discharged directly to sludge drying beds or sludge lagoons until the quality of supernatant improves. In situations where no preaeration equipment is provided, relief can sometimes be obtained by prechlorination of the sewage ahead of the primary sedimentation basin, if this is possible.

c. excessive fouling of surfaces and weirs with sewage solids or growths. Probably the best way to control slime growths on weirs and effluent launders is to increase the frequency with which these surfaces are hosed down. It is sometimes necessary to physically scrub these growths off of weir plates in particular. A long-handled, stiff-bristled street broom is ideal for this purpose. In some cases where the growths are particularly troublesome, prechlorination of sewage ahead of primary sedimentation basins may be effective in at least slowing down the rate of growth of such slimes.

d. broken scraper chains and/or frequent shear pin failure. Unless the sludge collection mechanism is badly out of alignment or adjustment, frequent shear pin failures or tripping of mechanical overload devices is indicative of poor sludge removal practices. If the removal of sludge at a more rapid rate does not cure the problem, then the mechanism itself is suspect and the entire sedimentation basin should be dewatered and the mechanism inspected in order to determine the cause of overload. Usually this may be traced to improper adjustment of plows on circular clarifiers or improper alignment of chains or insufficient clearance on scraper flights on rectangular basins. In some plants located in extremely severe climates, ice may form at the water surface along the sedimentation basin walls. This ice must be periodically broken up and removed before accumulations become thick enough to impede the motion of the sludge collector mechanisms. In some cases, overloading of sludge collector mechanisms may be due to large amounts of grit entering the system. If dewatering of the tank indicates large accumulations of grit or if large concentrations of grit are noticed in raw sludge which is pumped from the basin, grit removal equipment should be inspected and revised to provide proper operation if necessary.

e. sludge hard to remove from sludge hoppers. This symptom may be caused by high concentrations of grit in sludge or may also be caused by insufficient pumping rate of sludge from primary clarifiers. As a temporary expedient, compacted sludge in hoppers may be jetted with either air or water in order to loosen the material so that it may more easily be pumped. However, this will not cure the cause of the problem. In some cases, sludge suction lines between sedimentation basins and pumping facilities may accumulate deposits of sludge or grease which effectively reduce the area of the lines. If sludge is hard to remove from sedimentation basins and the sludge hoppers are found to be reasonably free of compacted material, the suction lines should be suspected and cleaned as required. In some cases, sludge suction lines may be effectively cleaned by backflushing with a hot, soapy water solution. In other cases, the design may have included cleanout branches through which mechanical pipe cleaners can be inserted. Care must always be taken when opening cleanouts which may be located below the water surface in sedimentation basins since the possibility exists that once a stoppage is cleared, tank contents may drain out through the cleanout thus flooding below grade pump stations or control rooms.

(3) scum collection and removal. A scum barrier or baffle normally is provided somewhere in the flow path between the influent and effluent portions of the tank. There will be less carry-over of scum and floating material if the scum is removed before appreciable amounts are allowed to accumulate against the scum barrier. Excessive skimming, however, will result in too much water being carried over with the scum. Insufficient skimming, on the other hand, will allow scum to exit from the tank and possibly cause problems with other treatment processes. In sedimentation basins equipped with automatic skimming devices, care must be taken to properly adjust the devices so that unneeded amounts of water are not removed with the scum. Clearances must be maintained in order to prevent possible structural damage to mechanical equipment. Where manual skimming devices are provided, these should be operated once

per complete revolution of the plows or scraper flights in such a way as to remove the majority of the collected scum. The practice of attempting to remove all scum present each time the skimmers are operated will result in excessive amounts of water being taken with the scum. The amount of scum which must be removed varies from one plant to another and each operating staff must determine by experience the best scum removal program for their particular plant and waste.

(4) weirs, launders, etc. The purpose of weirs as provided on sedimentation basins is to assure uniform flow in all areas of the tank provided with weirs. In the case of circular basins, this means that flows should be distributed equally around the entire circumference of the unit and in the case of rectangular units, it means that flow is uniformly taken off over the entire surface of the tank which is provided with weirs. Since the purpose of the weir is to ensure uniform flow rates, it can be easily seen that weirs must be kept level and fairly clean. If floating materials such as rags or scum are allowed to build up on the weirs, or if the weirs are allowed to support a heavy growth of slime organisms irregularities in effluent flow will occur. It is therefore necessary to periodically clean weirs to reduce this possibility. Effluent launders should also be kept clean and free of excessive slime growth. Slime growths in the effluent weirs will not appreciably detract from overall treatment efficiencies; however, the slime growths are unsightly and may give rise to offensive odors. Cleaning of both effluent launders and weirs is best accomplished by the use of a high pressure water jet and scrubbing with a stiff-bristled brush. Operators will find that it is much easier to clean these items periodically before large build-ups occur than to wait until excessive amounts of material have accumulated.

2. Chemical Treatment Units.

A. Flash Mixers and Flocculators. Where chemical treatment is practiced, the first two units in the flow pattern usually consist of a flash mix basin followed by a slow mixing or flocculation chamber. Usually the process follows screening and grit removal and precedes sedimentation; however, it may follow sedimentation in other cases, particularly where large quantities of easily settleable materials are present or where oils and greases are removed earlier.

Flash mix and flocculation equipment is also sometimes used in tertiary treatment plants following complete secondary treatment. The flash mix time is usually very short, ranging from less than one minute to about three minutes. Flocculation times vary from five minutes to one hour depending upon the specific process being employed.

Many chemical additives are commonly used in processes employing flash mix and flocculation. Among the most popular are alum, ferric sulfate, ferric chloride, ferrous sulfate, ferrous chloride, and lime. Recently, in the use of high molecular weight polyelectrolytes has become popular and it is anticipated that the use of these polyelectrolytes will increase in the future. Flash mix and flocculation equipment is usually mechanical in nature although sometimes diffused air is used for this purpose. In the case of mechanical equipment the manufacturer's instructions should be strictly followed as regards lubrication and maintenance. The basins containing this equipment should be dewatered at least yearly, and all submerged equipment should be checked for signs of wear and corrosion. In particular, flocculation basins may tend to accumulate sludge on the bottom of the basins due to poor velocity gradients. This sludge must be removed as required before it impairs the efficiency of flocculation. In plants equipped with air diffusion devices, it is necessary to periodically inspect the air diffusers to assure that free flow of air is achieved. Usually inspection on a twice yearly basis will be sufficient.

B. pH Control. In plants where chemicals such as lime or various acids are fed to control pH of either raw wastes or effluent from various units in treatment works, routine operation must include sampling and pH testing on a regular basis in order to control the chemical being fed. Many plants which are equipped for pH control provide continuously pumped sample streams and automatic pH indication or recording equipment. pH measuring equipment is relatively sensitive and the electrodes which are immersed in the sample to be tested are subject to fouling or "poisoning" if they are used continuously. In plants which employ continuous pH measurement, it is advisable to check the electrodes against a standard buffer solution at least twice daily and to clean the various electrodes in use by soaking in appropriate solutions at least once every two weeks. Manufacturer's recommendations as regards the care of delicate electronic equipment such as pH meters should be strictly followed. In the event that originally supplied information is no longer available at the treatment plant, additional copies may usually be obtained by writing the pH equipment manufacturer giving model and serial number information which appears on the instrument name plate.

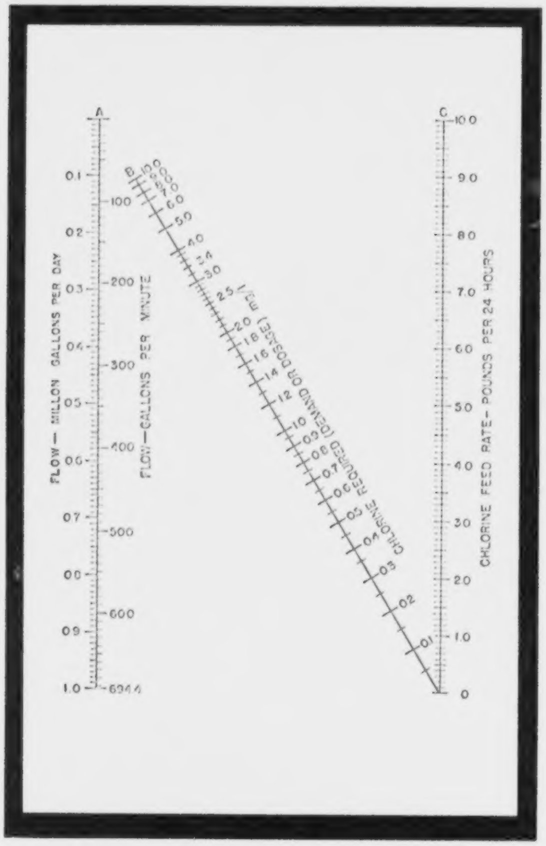
Pumps used to introduce chemical feeds should be lubricated and maintained according to manufacturer's instructions. If belt-driven variable speed drives are provided on the pumps, it is advisable to run the machine through the entire speed range from high to low at least weekly in order to prevent sticking of the variable speed pulleys in any one speed position.

GAS FEED CHLORINATOR
Figure (7-6)

C. Chlorination. **Chlorine is a Deadly Gas.** Operators should keep this fact in mind at all times when handling chlorine cylinders or chlorine feed equipment. Most treatment plants utilize gas-type chlorine feeders which withdraw chlorine from cylinders as a gas and inject the chlorine at the desired point of application as a chlorine water solution. Gas type chlorine feeders may be either manually or automatically controlled. Manually controlled chlorinators must be started and stopped by the operator whereas automatic or semi-automatically controlled machines start and stop themselves depending upon feed requirements, usually by means of a signal from a pump station or flow measurement equipment. In some cases, it is necessary for the operator to manually set the rate of chlorine dosage according to his best estimate of chlorine requirements, and the machine then turns on and off according to whether or not raw sewage pumps are in operation. In other cases, automatic rate setters are provided which adjust the machine so that a fixed amount of chlorine is injected for each increment of flow which passes through the plant. With this type of equipment, it is only necessary for the operator to determine chlorine requirements in terms of pounds of chlorine per million gallons of flow and set the machine accordingly. In the most sophisticated chlorine feed equipment a continuous sampling device measures the total chlorine content of the effluent from the contact basin and adjusts the machine to maintain a preselected residual. Any attempt to describe the intricacies of all of the various types of feed equipment used is beyond the scope of this basic manual. Operators should, therefore, have available complete descriptive literature supplied by the manufacturer concerning the various components of the feed system and equipment used at their particular plant. Any operator who does not presently possess such descriptive information should immediately contact the manufacturer of the particular equipment used requesting information. It is always helpful to give serial numbers and as much information as is possible about the various pieces of equipment when requesting such information. Operators who may be unsure whom to contact will find that Pollution Control Commission personnel and/or the consulting engineering firm which designed the treatment works can be quite helpful in obtaining new supplies of manufacturer's information.

Operators should also have available a copy of the manual published by the Chlorine Institute concerning chlorine handling and feeding. Copies of this manual may usually be obtained at no charge through the company which supplies chlorine to the treatment works. Figure 7-7 is a chlorination control nomogram which may be used by operators in order to quickly determine the pounds of chlorine required to be fed per day at varying dosage rates and varying flows. The use of this nomogram is as follows: Select the average daily flow rate, either in terms of millions of gallons per day or gallons per minute on Line A of the chart; and select the required dosage rate in terms of milligrams per liter on Line B. Connect the points selected on Line A and Line B by a straight line, and extend this straight line through Line C of the chart. The point where the straight line passes through Line C of the chart will give the required chlorine feed rate in terms of pounds of chlorine per 24 hours. In plants having daily average flows in excess of one-tenth of a million gallons per day, the chart may be used by dividing the average daily flow rate by 10 or 100 as required and multiplying the answer obtained on Line C by 10 or 100 as required. This division or multiplication by 10 or 100 involves only moving of a decimal point one or more places to the left or right. This operation is extremely simple.

As previously discussed all chlorination feed equipment should be maintained in strict accordance with manufacturer's instructions and particular care should be paid to the maintenance of all chlorine piping. Moist chlorine gas is extremely corrosive in nature. Because of this, should any chlorine leaks occur in chlorination feed rooms, exposed metal and particularly electrical contacts would be subject to very rapid corrosion. For this reason, chlorine feed rooms are always separately ventilated from other rooms within treatment works structures and only absolutely essential equipment is housed within the chlorine feed room. Usually all electrical equipment is of the explosion-proof type. This type of equipment is used to protect the equipment from corrosion should leaks occur rather than to prevent explosions from occurring.



CHLORINE FEED NOMOGRAM
Figure (7-7)

Chlorine is available in 150-pound cylinders and in large, ton containers. The cylinders or ton containers are not completely filled with liquid chlorine at the point of manufacture and when received at the treatment works, will contain chlorine in both the liquid and gaseous form. Since gaseous chlorine expands when subjected to heat, cylinders or ton containers must never be subjected to direct heat or allowed to stand exposed to direct sunlight during summer months. Exposure to excessive heat can generate sufficient pressure within the chlorine cylinders to blow out the safety plug installed in all chlorine cylinders or containers thus releasing chlorine to the atmosphere.

Valves provided on chlorine cylinders or containers should always be covered with the cap which is provided at all times when the cylinder or container is not actually in use to avoid the possibility of breaking the valve stem off, thus releasing chlorine to the atmosphere. In the event that an operator is ever faced with a chlorine cylinder which has ruptured, either because of a faulty valve or because the soft plug has been blown out, the room in which the cylinder is located should be immediately sealed off if possible; and the operator should put on the gas mask before attempting to control the leak in any way. In the event that a cylinder ruptures in an outside location, the operator should immediately put on a gas mask and, if possible, attempt to roll the cylinder into a position where only gaseous chlorine will escape rather than liquid chlorine. Never apply water to a chlorine leak or to a leaking container because this will usually cause very rapid corrosion to take place at the point of the leak. If a drastic leak such as failure of a cylinder or container soft plug occurs, thus releasing large amounts of chlorine to the atmosphere very rapidly, it is advisable if possible to immediately roll the cylinder into the nearest water-containing basin. All mechanical equipment operating within the basin should, of course, be shut off as quickly as possible. Once rolled into the basin, the cylinder itself will most likely be severely damaged; however, the amount of gaseous chlorine which will escape to the atmosphere will be remarkably reduced because the majority of chlorine will go into an aqueous solution in the water-holding basin. If a serious chlorine leak develops which cannot be quickly repaired by the operator, local authorities such as the police department or sheriffs department should be immediately notified and all surrounding residents who might be endangered by the escape of chlorine gas to the atmosphere should be evacuated. The chlorine supply company should be notified as soon as possible in case of emergency.

3. **Biological Treatment Units.**

A. High Rate Filters.

(1) rotory distributors. Orifices or nozzles on rotating arms should be inspected daily for clogging and cleaned if necessary. Bearings should be checked and maintained in accordance with manufacturer's recommendations. Guy rods or guy wires should be adjusted with seasonal temperature changes to keep the distributor arms in a horizontal position. If the filter must be shut down for any reason, drain the distributor arms in the central riser pipe by opening the valve provided at the base of the riser pipe. Draining of the distributor is espe-

cially important if shut down must be done during freezing weather. Distributor seals should be inspected monthly for signs of leakage or wear and repairs made according to instructions furnished by the manufacturer.

If the distributor is provided with a mercury type seal, the mercury should be drained and cleaned at least yearly. This should be done in accordance with manufacturer's instructions. If the distributor is provided with a grease seal the top bearing should be greased at least monthly, using the grease recommended by the manufacturer. The entire seal should be inspected and cleaned yearly. Many large rotory distributors are equipped with two rows of ball bearings and nearly all distributors have at least one row of ball bearings. Oil levels for these ball bearings should be checked at least monthly and oil added as required using the oil as recommended by the equipment manufacturer.

(2) fixed nozzle distributors. Routine daily operation should include inspection of all nozzles and cleaning of those clogged or partially clogged. To clean a nozzle, the jet and cone should be removed and punched clean with a wire or a rod. At not less than weekly intervals the distribution lateral should be flushed for a few minutes by removing the nozzles at the end of the laterals. The main pipes distributing flow to the laterals should also be flushed by opening the valves provided for this purpose.

(3) dosing siphons. Dosing siphons are intended to discharge intermittently. If they discharge continuously, a siphon chamber vent is probably clogged. This should be remedied at once. To prevent faulty dosing tank operation, the tank should be cleaned regularly and leaky or corroded pipe should be replaced. Slime and grease should be washed from the walls and piping daily, and the bottom of the tank should be stirred weekly. If compressed air is available the dosing tank piping may be blown out at regular intervals. If the dosing tanks are equipped with dosing counters with float attachments, these should be cleaned and oiled weekly. In winter it may be necessary to cover dosing tanks and siphons to retard ice formation in the tank.

(4) filter media. Leaves and other wind blown materials that may collect on filter surfaces should be removed immediately to prevent possible clogging of the filter or interference with distribution and aeration. Removal of nearby trees may be necessary in order to solve the leaf problem. In some climates it may be necessary to remove snow and ice from trickling filters operated in the winter.

The media surface should be visually inspected daily to determine whether or not pools of water tend to stand at any portion of the surface area of the filter. The condition where water stands over the entire filter surface or in any isolated pockets is termed ponding. This condition will effectively prevent the free passage of air through the filter thus depriving the organisms responsible for treatment of the necessary oxygen supply. Ponding may be caused by very prolific growths of organisms within the filter or by clogging of the void spaces within the filter by the discharge of too many solids onto the filter surface. Ponding may also be caused, in some cases, by the breaking up of the filter media due to freezing and thawing if high grade media was not originally installed in the filter. Filter ponding caused by discharge of solids onto the surface of the filter may most easily be controlled by increasing the efficiency of primary sedimentation basins or by installing additional sedimentation basin capacity if required. In some cases, the addition of polyelectrolytes into the sewage flow ahead of the primary sedimentation basin, may increase sedimentation efficiency sufficiently to allow existing basins to handle increased loads.

If ponding is caused by excessive growths of organisms within the trickling filter, an increase of recirculation rate through the filter may prove helpful. In addition, the use of polyelectrolytes ahead of primary sedimentation may decrease the overload to the filter which is responsible for the excessive growth. Filters which have become ponded should be taken out of operation and rested if possible without bypassing of sewage. The surface of the media should be flushed with high pressure fire hoses as well as mechanically raked and jetted using forks or iron bars. In addition, the application and recirculation over the filter surface of high strength chlorine solutions will sometimes remove the excessive growth from the filter media. If chlorination is practiced, very high recirculation rates should be used in order to attempt to flush all material which is removed from the filter media through to the underdrain system. If ponding is caused by breaking up of the filter media, the only lasting remedy is to remove the media, test it for soundness, and rescreen. If it is found to be reusable replace the media in the filter. When the existing media is found to be unsuitable for reuse, new media must then be installed. Heavy equipment such as tractors and loaders should never be allowed on the surface of filters since their operation will undoubtedly cause damage to the media or the underdrain system or both.

(5) filter flies. Occasionally trickling filters are found to breed tremendous quantities of insects commonly called filter flies. Many older trickling

filters are designed so that the entire volume of the filter may be flooded periodically. Flooding of this type of filter at approximately two-day intervals will usually control filter flies. Most present day trickling filters are not designed to be flooded and flooding of such units could result in extensive structural damage to the concrete filter walls. Usually it is found that trickling filters which are operated on a continuous basis with reasonably high recirculation rates do not breed extensive filter fly populations. In the event that infestations do occur, however, they may be easily controlled by intermittent chlorination of the filter surface or by use of various insecticides such as DDT, Filtrex or other commercial products. Insecticides should never be used unless the specific recommendations of the insecticide manufacturer or supplier are followed. The use of chlorine or insecticides usually will result in a lessened efficiency of the trickling filter for some period of time until residuals are washed from the media, because neither the chlorine nor the insecticide are selective in action. Although the filter flies will be killed, considerable amounts of the desirable organisms living on the filter media will also be killed.

Filter walls should be washed down frequently, at least daily, during the summer months; and weeds or grass growing near the filter walls should be kept neatly mowed. This will help to control filter fly breeding. Where high-rate trickling filters are employed, it is often possible to operate the filters provided either in parallel or in series. If filters are operated in series, the lead filter or filter which first receives settled sewage should be alternated if possible on a weekly basis during periods of high load.

B. Standard and Low Rate Filters. Operation and maintenance of low rate trickling filters is essentially the same as that previously described for high rate filters.

C. Roughing Filters. In plants which employ roughing filters as a method of reducing load to following secondary treatment units, particular care must be taken that ponding does not occur. If a plant is so designed it is advisable to alternate lead filters so that each filter is used only part of the time as the roughing filter. If a plant is designed so that only one filter may be used as a roughing filter particular attention must be paid to this filter in order to assure that ponding does not occur. If the waste loads are such that it is not necessary to utilize the roughing filter during the entire year, it is often advisable to take the roughing filter out of service at times when waste loads are reduced and to chlorinate the filter in a manner as previously described so that when the filter is again placed into operation, excessive growths will have been removed. Filters which are taken out of service and allowed to remain idle for some time should not be allowed to have the underdrain system stand partially filled with water. This may provide an excellent breeding place for mosquitoes and other insects. In other respects, operation and maintenance of roughing filters is similar to that previously described for high rate trickling filters.

D. Standard and High Rate Activated Sludge Units.

(1) basic requirements. As previously described, good operation of any activated sludge system can only occur if the activated sludge contains adequate numbers of purifying organisms; dissolved oxygen is present in sufficient concentrations and in all portions of the aeration tanks; and the activated sludge separates readily from the treated sewage in final sedimentation basins.

(2) activated sludge organisms. For successful operation, there must be contained within the aeration basin, a sufficient quantity of activated sludge organisms to assure that soluble pollutants in the waste fed to the aeration basin will be fairly quickly removed and utilized as a source of food and energy by the activated sludge organisms. The mixed liquor suspended solids concentration test described in another section of this manual is used as a guide to express the concentration of activated sludge organisms in any aeration system. Required concentrations of mixed liquor suspended solids vary from plant to plant because of variations in waste strength, detention time, and specific activated sludge process used. In general, most standard and high rate activated sludge plants will require that mixed liquor suspended solids concentrations between 1,000 and 3,000 milligrams per liter be maintained if effective treatment is to result.

(3) return sludge. In order to maintain required mixed liquor and suspended solids concentrations, it is always necessary to recirculate sludge separated from aeration basin effluent in final sedimentation basins back to the aeration basin. The rate of return sludge is usually expressed as a decimal fraction of the incoming waste to the aeration basin. Return sludge must be applied to the aeration basin in sufficient quantities to maintain mixed liquor suspended solids concentrations in the aerator at required levels. Usually from 20 to 50 percent of the influent waste flow to an aeration basin must be recycled in the form of return activated sludge.

(4) dissolved oxygen. Sufficient dissolved oxygen to maintain a minimum concentration of about 1.5 milligrams per liter dissolved oxygen in

aeration basin effluent must be supplied if activated sludge processes are to operate properly. If dissolved oxygen concentrations in the aeration basins are allowed to fall significantly below 1.5 milligrams per liter, fungi and other stringy types of organisms which are very difficult to settle from aeration basin effluent will predominate. Under these conditions, treatment efficiency will fall rapidly and the net result may be complete failure of the activated sludge system until such time as regrowth of desirable organisms can be stimulated. On the other hand, dissolved oxygen concentrations much in excess of 1.5 milligrams per liter serve no useful purpose and in fact are felt to be harmful by some authorities. Even if high dissolved oxygen concentrations are not harmful, they certainly represent wasted energy which in turn represents unnecessary expenditure of money.

(5) final sedimentation basins. Final sedimentation basins are always employed following aeration basins in activated sludge systems. The purpose of the final sedimentation basin is to remove the activated sludge organisms from the aeration effluent, concentrate these organisms for return to the aeration basin or for wasting, and to discharge clarified effluent for additional treatment such as chlorination. In order for final sedimentation basins to perform their intended functions in the activated sludge system, it is necessary that the aeration basin effluent contain activated sludge organisms which settle readily. The sludge volume index test as described in another section of this manual is used to describe and measure the settling characteristics of the activated sludge flocs. Normally, sludge volume indexes in the range of 100 to 150 indicate good settling characteristics and good operation of activated sludge systems. Aeration basin effluents which exhibit the sludge volume indexes greater than 200 exhibit poor settling characteristics and usually are an indication of improper operation or other difficulties with the activated sludge system.

(6) sludge wasting. Activated sludge organisms accumulate in activated sludge systems more rapidly than is necessary for proper operation. Accordingly, in most activated sludge systems a portion of the return activated sludge must be bled from the system. This sludge which is removed from the system is termed waste activated sludge and is usually pumped to digesters or other units for additional treatment. The amount of sludge which must be wasted varies from plant to plant according to the process being used, the strength of incoming wastes and detention time provided in aeration basins. The sludge age test described in another section of this manual may be used as an indirect method to describe the amount of sludge which must be wasted. Sludge ages of from 3 to 6 days are commonly used in standard and high rate activated sludge systems. Since sludge age is defined as the quotient obtained by dividing the total pounds of solids under aeration by the pounds of solids wasted per day, it may be seen that if an activated sludge plant is operated with a sludge age of 5 days, wasting requirements would be equivalent to one-fifth of the total pounds of solids under aeration each day. As an example, if an aeration basin had a volume of one million gallons and was being operated with a mixed liquor suspended solids concentration of 2,000 milligrams per liter, the total weight of solids under aeration would be equivalent to 8.34 times 2,000 or 16,680 pounds. If the sludge age were 5 days, then the daily wasting requirement would be 3,336 pounds of dry solids. If this weight of dry solids were to be wasted each day in a flow containing only one percent solids, a total of 33,600 pounds of liquid sludge would have to be pumped from the system each day. If this sludge were to be wasted on a continuous basis dividing the pounds of liquid per day by 1,440 (the number of minutes in a day), one could determine that approximately 234 pounds of liquid would have to be wasted each minute of each day. Dividing the pounds of liquid to be wasted by 8.34 (the approximate weight of one gallon of waste activated sludge) one could determine that a sludge wasting rate of approximately 40 gallons per minute would have to be maintained on a continuous basis. Because it is extremely difficult to obtain very high solids concentrations in waste activated sludge, it is normal practice to either introduce the sludge to be wasted into sludge thickener for further concentration or in some cases to discharge the waste activated sludge back to the primary clarifiers wherein the material may be concentrated and removed along with primary sludge.

(7) aeration equipment. As previously described, aeration equipment may be either of the diffused air type or the mechanical aeration type. Where mechanical aerators are used, routine maintenance should include daily checking of oil levels and gear boxes and greasing on a regular schedule as recommended by the equipment manufacturer. Since mechanical aerators are normally installed exposed to the weather, a regular program of painting or other protective coating maintenance is required to prevent corrosion. Where diffused air systems are used, it is necessary to inspect air diffusion devices regularly and to clean them as required in order to assure free flow of air through the systems. Those systems which employ fine bubbled diffused air aeration are

usually provided with a system of filters placed ahead of the air compressor intakes. These air filters must be inspected and cleaned or replaced on a regular basis according to the manufacturer's instructions. It is common practice to provide manometers or other loss of head indicating devices in such a manner that the condition of the air filter may be determined by reading the loss of head between the upstream and downstream sides of the air filtration system. High head losses through the air filtration system are indicative of a dirty filter. If this occurs, the filter must be either cleaned or replaced. Air blowers used in air diffusion systems may be either of the centrifugal or positive displacement type. In either case, daily checks of oil levels in gear boxes and lubrication systems are required and routine lubrication should be practiced in accordance with the manufacturer's recommendations.

Where positive displacement type blowers are used, it is common practice to provide valving on the downstream side of the compressor so that the compressors may be started under no-load conditions. These valves should be opened prior to placing any compressor into operation and then closed as the compressor comes up to speed. Where positive displacement compressors are used, operators should take particular care to ensure that air control valves, both upstream and downstream on the compressor, are in the open position at any time that the compressors are in operation. If the suction or discharge side of positive displacement compressors is closed, severe damage to the compressor equipment will be inevitable. Operators should pay particular attention to unusual noises which may occur during compressor operation as an indication of impending failure of the compressor equipment.

Where centrifugal type compressors are utilized, air control valves on the downstream side of the compressor are usually provided. Centrifugal compressors may be safely throttled (that is the control valve may be partially closed when the compressor is in operation). Throttling will result in air discharges of less than full capacity. Operation under partially throttled condition will require less horsepower, and accordingly this method offers at least partial control of air flow at reduced power costs. Partial throttling of centrifugal air compressors will result in increased temperature of discharged air. It is normal practice to install thermometers on the discharge side of all compressors so that operators may rapidly check air temperatures. Allowable air temperatures vary according to the make of compressor being utilized; however, in general it is good practice to keep discharge temperatures below 170 degrees Fahrenheit.

(8) aeration basins. Routine operation of aeration basins should, of course, include the usual housekeeping measures as described for other water holding basins such as sedimentation basins. In addition to washdown by hosing and brooming of overflow weirs if required, it is sometimes necessary to control foaming in aeration basins. Foam control in aeration basins is usually accomplished by intermittent operation of water spray systems. Occasionally, the problem becomes so severe as to require continuous operation of the foam-breaking sprays; and it is sometimes necessary to mix various foam suppressants into the water supply which operates the spray system. Foam should not be allowed to cover walkways or become coated on equipment since the foam frequently contains significant amounts of grease. Foaming has usually been found to be more severe in activated sludge plants where very low mixed liquor solids concentrations are maintained and less severe in those plants which operate at fairly high mixed liquor solids concentrations. Since foam spray systems can quite often introduce significant volumes of flow into an aeration basin, it is not good practice to operate the foam suppressing sprays more than is actually required. If aeration basins are provided with scum baffles to prevent overflow of floating material from the aeration basin, it is usually necessary to periodically hand skim floating materials which may collect. Skimmings should be disposed of in the same manner as scum collected from the surface of primary clarifiers. It is considered good practice to periodically dewater aeration basins in order to remove accumulations of heavy solids and/or grit. Cleaning can be accomplished in the same manner as previously described for sedimentation basins. The same precautions with respect to flotation of empty aeration basins should be observed as have been previously described for sedimentation basins. All submerged and non-submerged iron metal surfaces should be subjected to a routine program of painting or other protective coating. If drain valves are located in activated sludge basins they should be operated occasionally in order to assure that the valves do not stick in the closed position.

(9) final sedimentation basins for activated sludge systems. Operation and maintenance of final sedimentation basins associated with activated sludge systems should be performed as previously described for primary sedimentation basins. In cases where the sludge suction type of mechanism is employed, it may be necessary to periodically backflush the sludge suction drawoff pipes in order to ensure that they have not become plugged. On those clarifiers which employ a depressed center

launder for the purpose of removing activated sludge from the tank bottom, routine maintenance should include checking of the rotating seal and adjustment as required in order to prevent large volumes of clarified liquid from leaking into the return sludge system.

If suction type clarifiers utilizing adjustable drawoff pipes are employed the various drawoff pipes should be adjusted to pull the thickest possible concentration of return sludge solids from each individual drawoff point. Usually this will require that more volume of return sludge be removed from those drawoff points closest to the center of the clarifier and less return sludge from those drawoff points closest to the outer circumference of the clarifier. All such individually adjustable systems should be operated at least weekly in order to ensure that the threaded ring arrangement does not freeze in one position thus making future adjustment difficult or impossible.

Most final sedimentation basins for activated sludge plants are not equipped with skimming devices. Accordingly, it is sometimes necessary to divert surface scum to one section of the clarifier by use of a water hose, then remove it by hand skimming methods. Usually a small amount of floating surface material is not particularly harmful to the effluent and small quantities will easily pass over the weirs without causing problems.

As with all mechanically equipped sedimentation basins, the tanks should be dewatered at least on an annual basis and mechanisms and tank structures completely inspected, painted, and repaired as required.

(10) operation troubles.

a. bulking sludge. Occasionally activated sludge systems exhibit a tendency to produce activated sludge which has very poor settling characteristics as indicated by high sludge volume indexes. Usually increasing sludge volume indexes are caused by a low concentration of mixed liquor solids in the aeration basins; a high BOD loading in the aeration basin; insufficient essential nutrients in the waste to be treated or by insufficient dissolved oxygen content in the aeration basin. Although there is not complete agreement among experts, some authorities believe that prolonged aeration at extremely high dissolved oxygen contents also tends to increase the sludge volume index. Activated sludge which exhibits poor settling characteristics is said to be bulking. When operators are faced with a bulking sludge, it becomes extremely difficult to produce satisfactory effluent. The entire system may fail because it is not possible to return sufficient activated sludge to the aeration system in order to maintain proper mixed liquor suspended solids concentration. When this occurs, operation becomes progressively more and more difficult because with insufficient solids concentration in the aeration basin, the tendency for sludge to bulk increases. If dissolved oxygen tests indicate that at least 1.5 milligrams per liter are available in all parts in the aeration basin, the cause is definitely not a lack of dissolved oxygen. Assuming that there is no lack of essential nutrients for the sludge, the problem usually can be laid either to too high an organic loading in the aeration basin, or to insufficient solids concentration in the aeration basin. Obvious remedies for these causes include increasing the sludge recirculation ratio and decreasing the amount of sludge being wasted temporarily until proper operating conditions are once again established. Bulking of activated sludge may sometimes be controlled by judicious application of chlorine to return sludge. The dosages generally found effective are in the range of from 10 to 20 milligrams of chlorine per liter on the basis of the volume of the returned sludge. A more satisfactory way of dosing and expressing the results would be on the basis of dry solids in the return sludge. On this basis effective dosages of chlorine are from 0.003 to 0.006 pounds of chlorine per pound of dry solids returned. Another method which has had limited success in controlling bulking sludge has been to introduce small quantities of digested sludge into the aeration basin system. This may serve two useful purposes; it provides a source of heavier sludge material which tends to weight down the activated sludge floc; and it also, in some cases, supplies a readily available source of nitrogen which may be lacking in the waste being treated. If the practice of returning digested sludge to aeration basins is used, operators should be aware of the fact that substantial increases in the amount of oxygen required may be necessary and care should be taken to ensure that dissolved oxygen concentrations in the aeration basins are not allowed to fall below 1.5 milligrams per liter.

b. sludge rises in final sedimentation basin. The usual cause of gas lifting of sludge in final sedimentation basins associated with activated sludge plants is the failure to remove sludge from the basin at a fast enough rate. In the absence of adequate dissolved oxygen activated sludge organisms may turn to chemically bound oxygen in the form of nitrates as an oxygen supply. This phenomenon is called denitrification and results in the liberation of nitrogen gas which tends to lift sludge particles to the surface of final sedimentation basins. The obvious remedy is to increase recirculation rates to cut down the period of time which the activated sludge actually spends in the sedimentation basin. If this cannot be done, it may be advisable to remove a portion of the aeration basins provided from service. This action will result in less nitrification in the activated sludge process; and accordingly, there will be less nitrates available as a source of chemically bound oxygen.

In the event that aeration basins cannot be removed from service, the same effect can be brought about by decreasing the mixed liquor suspended solids concentration so that the effective BOD loading per pound of mixed liquor solids concentration in the aeration basin is increased. This action also tends to decrease the rate of nitrification in the system.

E. Extended Aeration Units. Extended aeration units are usually small capacity plants which normally provide approximately 24 hours aeration for incoming wastes. Because of the long detention time provided, extended aeration units are normally operated at fairly low mixed liquor suspended solids concentrations and very little waste activated sludge is produced.

One of the most common problems with the extended aeration activated sludge systems, is the gas lifting of sludge in the final sedimentation basins provided. Usually in these plants the final basins are not mechanically equipped and the problem generally can be traced to plugging of the sludge recirculation equipment provided with the plant. The obvious remedy here is to maintain the return sludge system in as clean a condition as possible and to perform routine maintenance to ensure that plugging does not occur. Basically other routine maintenance on this type of system is similar to that described for standard and high rate activated sludge systems.

F. Contact Stabilization Units. Contact stabilization units as previously described, usually consist of two separate aeration basins. In the first aeration basin, activated sludge which has been aerated for a considerable period of time is contacted with incoming wastes for a period of from 30 minutes to 1 hour. Quite often, contact stabilization plants are not equipped with primary clarifiers and because of this, considerable floating scum may be present in the aeration section. Routine operation may make it necessary to manually remove this floating material from this section unless skimming devices are provided on the final sedimentation basin following the contact basin. The second aeration basin provided in most contact stabilization plants, is used for the purpose of reaerating returned sludge for a period of 5 hours or longer. In this basin, the activated sludge actually decomposes food materials which have been absorbed onto the activated sludge flocs in the contact basin. Good operation of the reaeration section demands good mixing action and sufficient dissolved oxygen to maintain at least a 1.5 milligram per liter dissolved oxygen concentration in the reaeration basin. Final sedimentation basins associated with contact stabilization plants must be always operated in a manner to remove settled activated sludge as quickly as possible from the sedimentation basin for discharge into the reaeration section. Failure to remove activated sludge from the final basin will inevitably result in poor settling characteristics of the sludge in the basin and poor BOD removals for the entire system. Routine operation and maintenance of equipment provided in contact stabilizations is similar to that previously described for standard and high rate activated sludge units.

G. Aerated Lagoons. Operation of aerated lagoon systems is very much like the operation of extended aeration plants as previously described, since detention times in aerated lagoons are usually in excess of 24 hours. These systems almost always operate at fairly low mixed liquor solids concentrations, and quite often the systems are not equipped with final sedimentation basins but rather depend on settling within the aerated lagoon as a means of clarifying the effluent. Aeration devices in aerated lagoons are usually of the mechanically operated type. These units may be either mounted on floats or permanently mounted on structures in the lagoon. Routine operation and maintenance should be performed on all mechanical aerators as previously described in accordance with the manufacturer's recommendations. Particular care must be paid to mechanical aerators when these devices are operated during freezing weather conditions to prevent the build-up of ice on the impeller blades. Occasionally ice will tend to form on even rotating elements and this ice build-up may cause the machines to become unbalanced. If automatic devices are not provided to shut the devices off in cases of extreme weight imbalance, severe damage to the mechanism can result unless operators pay particular attention to this problem and manually shut down the machines. In cases where earthen ponds are provided as aeration basins in the aerated lagoon systems, routine maintenance should include dike inspection and mowing of grass. If final sedimentation basins are provided as a part of the aerated lagoon system, this equipment should be operated and maintained as previously described for standard and high rate activated sludge units.

H. Lagoons and Oxidation Ponds. Because lagoon or oxidation pond treatment systems usually have very little mechanical equipment associated with them, operation and maintenance of this type of treatment system is usually very simple. Dikes should be maintained in good condition and grass or weeds should be mowed regularly. The use of farm type sickle-bar mowers mounted on small tractors may be particularly advantageous for mowing purposes since the sickle bar may actually be extended under the water surface to ensure complete mowing of vegetation at the water line. It is particularly important to keep vegetation under control since weeds growing at the water line provide excellent breeding places for insects such as mosquitoes. The growth of aquatic vegetation from the lagoon bottoms may usually be easily controlled by maintaining water depth of at least 30 inches at all times during the growing season. Where lagoon systems are designed with more than one cell and both series or parallel operation are possible, it is usually found to be advantageous to operate the ponds in series during warmer periods of the year. Operation of ponds in series tends to minimize the amount of algae present in the last cell and may result in a better quality effluent. During winter months when biological activity proceeds at a much slower rate, it may be advantageous to operate multiple-celled installations in parallel so that incoming sewage solids are distributed throughout a greater area. This is particularly true if the installation is subject to ice cover during the winter months. If series operation is practiced during winter months, the first pond in series may become overloaded with solids and with the return of warmer weather this cell may exhibit septic conditions with resulting odor production and unsightly formations of scum and gas lifted sludge. Occasionally, burrowing animals have become a problem in lagoon and oxidation pond dikes. Trapping and selective poisoning of these rodents is usually a fairly effective means of control. Some operators have found that the use of cartridges which liberate cyanide gas upon burning may be effectively used to control larger rodents such as muskrats. These cartridges are simply inserted into exits of tunnels made by the rodents, lighted and the exit hole covered with dirt. The cartridge then ignites inside the tunnel and liberates cyanide gas throughout the tunnel network thus killing the rodents. All types of poisons which may be used should, of course, be handled with extreme care and the manufacturer's instructions should be strictly followed.

I. Anaerobic Sludge Digesters. It is not practical to cover all of the special problems which may develop in the operation of sludge digestion units in this operating manual. There are, however, many routine procedures which usually give the best results with heated sludge digestion tanks which are the most common. A number of these operating and maintenance procedures are listed below.

(1) sludge pumping. Sludge should be drawn from sedimentation units before it has become septic and should be as dense as possible and still handle satisfactorily through the pumps and piping. A thin sludge contains excess water which occupies storage space and will have to be heated.

Sludge should be added to the digester at frequent intervals, perhaps by use of an automatic time clock control. Small additions of sludge at frequent intervals assures a more constant food supply to the organisms and a more uniform digestion rate. With fixed cover digesters, the rate of addition should be low to minimize disturbance of the supernatant which is discharged from the digesters at the same rate at which sludge is added. This is not so important with digesters equipped with floating covers since the supernatant is not necessarily discharged at the same time. In general, fresh solids (dry basis) added daily should not exceed 5 percent of the solids (dry basis) already in the digester. If this 5 percent value is held to as a maximum sludge addition rate, simple arithmetic will indicate that theoretical detention time in such a digester would be 20 days. This is usually sufficient time for first stage digestion to occur at temperatures between 85-98°F.

(2) two-stage digester operation. Two stage digestion uses two compartments or two tanks (more if units are operated in parallel) which separate the digestion phases. In the primary or first digestion tank, incoming raw sludge is well mixed with seeding material and the tank contents are kept well mixed by use of mechanical stirrers or gas recirculation. Some sludge separation normally occurs in spite of mixing with the heavier material settling to the bottom of the tank. The digestion process is completed in the secondary tank where there is much lower gas production which causes less mixing and produces a much clearer supernatant than can be produced in a single stage digester. In using two stage digestion with fixed cover primary digester, the supernatant or lighter sludge is normally transferred while raw sludge is being pumped to the primary digester causing overflow of this material to the secondary digester through the supernatant transfer line. The supernatant and digested sludge is withdrawn from the secondary digester in the same manner as is done with a single digester. If the primary digester is upset and the pH drops, sludge may be pumped from the bottom of the secondary digester to the primary to provide additional seed and thus maintain alkaline digestion conditions. Supernatant must be transferred from the primary to the secondary digester simultane-

ously. The temperature in the secondary digester is normally maintained approximately 10 degrees Fahrenheit or more below that of the primary digester to improve supernatant separation. Under normal conditions, this makes heating of the secondary digester unnecessary except during the coldest parts of the year. However, if complete digestion is not being obtained, digestion rates in the secondary digester may be increased by heating that unit In using two-stage digestion with a floating cover, the primary digester may be operated the same as the fixed cover type with automatic supernatant or light sludge transfer through the overflow piping. As an alternate the transfer may be made every two or three days. In other respects, operation is similar to that with a fixed cover primary digester.

(3) temperature control. The temperature in the digester should be maintained within a range of two or three degrees of that selected. This is usually between 85 and 98 degrees Fahrenheit. With heating coils in the digester, the temperature of the water and the coils should be high enough to maintain sludge temperature but not over 130 degrees Fahrenheit. (At temperatures of 140 degrees or over the sludge will cake on the coils and form an insulating layer, thereby reducing the efficiency of heat exchange.)

(4) pH control. The reaction of the sludge should be kept within a pH range of 6.8 to 7.2. Some experts advocate adding lime to neutralize sludges which are too acid while others say that lime has no place in a digester. The addition of lime certainly is not a cure-all for acid sludge. However, lime may be used in emergencies in order to raise the pH. If lime is added, it should be added in small increments as a liquid slurry. A fairly convenient method of adding lime solution to a digester is to mix the lime solution in a scum pit of a primary clarifier and then pump the contents into the digester. Primary digesters which are chronically found to be in acid condition are probably overloaded and a better means of control can be had by proper control over the fresh solids input.

(5) mixing. Where available, mixing devices should be used either continuously or at frequent intervals to assure adequate seeding of fresh solids in primary digesters. This will give more rapid and uniform digestion, help to prevent scum formation and lessen the possibility of foaming difficulties.

(6) withdrawal of supernatant. Supernatant is the digester liquid lying above the sludge solids in a digester. While it should contain some sludge solids, it is very high in dissolved organic matter which decomposes rapidly with the development of foul odors. Supernatant is generally returned to the head of the plant for retreatment. Supernatant is withdrawn from the digester to reduce the volume of liquid in the digester and to provide storage space for the addition of fresh solids. With fixed cover digesters, supernatant must be withdrawn at the same time and at the same rate that raw sludge is added. This is a further reason why raw sludge should be pumped for short periods at frequent intervals of time to digesters. The discharge of large volumes of supernatant in a short period of time to primary treatment units can as previously described cause septic conditions in these units.

It is important that supernatant outlets be kept clean. Particularly in the case of fixed cover digesters it is actually possible to damage the fixed cover if there is not some means for supernatant liquor removal available. With floating cover digesters, the safety of the cover is not a factor and it is possible to withdraw supernatant liquid at a low rate over long periods of time. Where the sludge is agitated by stirring devices or recirculation, it is desirable to allow a quiescent period of several hours before withdrawing supernatant.

There are a number of methods used for the disposition of supernatant. Probably the most common procedure is to return it to the influent of the primary sedimentation tanks. This may cause difficulties by causing the tank to become septic. At some plants it has been found advantageous to return the supernatant to the influent of an activated sludge aeration tank or trickling filter. If this practice is adopted, however, strict control must be maintained in order to assure that aeration basins are not upset and that filter media is not plugged by solids from supernatant liquid.

(7) withdrawal of digested sludge. The type of digester, subsequent sludge treatment, season of the year, and need for storage space for fresh sludge normally govern the withdrawal of digested sludge. It is important to leave enough digested sludge to seed the raw sludge and maintain balanced digestion for solids which remain in the digester. In heated digesters, the same amount of sludge may be left in the tank regardless of the season. In unheated digesters about twice the normal digested sludge contents should be retained as cold weather approaches. Withdrawal of small amounts of digested sludge at regular intervals is far preferable to large withdrawals at long time intervals. Only well digested sludge should normally be withdrawn from digesters. Gray or light brown streaks in dark colored or well digested sludge are signs that undigested material is being withdrawn.

Well digested sludge normally does not have an extremely disagreeable odor and usually smells somewhat musty rather than sulphurous or like rotten eggs. Where fixed covers are employed on digesters, it is of the utmost importance to ensure that no air is drawn into the tank during sludge withdrawal.

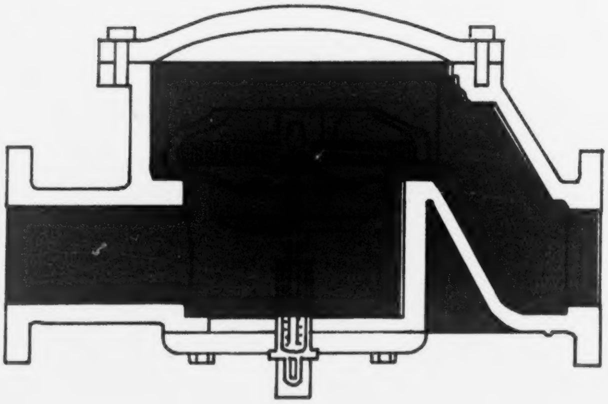
Care must also be taken in the withdrawal of sludge to avoid negative pressures in fixed cover digesters. This can be done by adding raw sludge, sewage, sludge gas or water from a make-up tank at the same rate that sludge is withdrawn from the digestion tank. The addition of air to digester gases produces a highly explosive and dangerous mixture. It is equally important to see that safeguards provided to prevent build-up of excessive hydrostatic pressure under a fixed cover are functioning. The most common provision is an unvalved supernatant overflow line which must be kept open at all times.

(8) scum control. Scum formations in digesters have the disadvantages of occupying volume needed for digestion and interferring with effective circulation, mixing, and temperature control particularly as the scum layer becomes extensive, occupying the space normally occupied by supernatant. This prevents selection and withdrawal of good quality supernatant and interferes with gas separation and collection.

Scum control normally falls into one or more of three general control measures. Scum blankets caused by oils and certain greases or other materials which will not digest readily are most easily prevented by elimination of these materials from the digester. Some of these materials should be eliminated or drastically reduced at their source. Examples of this type of material are crankcase drippings from filling stations and large amounts of greases and fats from restaurant operations. Most cities have adopted ordinances that this type of material not be discharged into sanitary sewer systems and if such ordinances have been adopted, control is usually best accomplished by enforcement of the ordinance. If occasional large oil spills find their way into the sewer system, it is preferable to skim this material from the surface of primary sedimentation units and to dispose of the skimmed material by incineration or burial rather than by pumping into the digester. If absolutely necessary, undesirable materials floating on the surface of digester contents may sometimes be removed through manholes in the digester cover. Oils so removed should be burned if practicable; greases and other fatty materials should be buried; and fibrous materials may be dewatered on drying beds or lagoons for disposal with digested sludge. Usually the best control measure for scum formations will be found in thorough mixing in primary digesters thus causing more effective digestion. In cases where existing plants do not have mixing facilities available, installation of recirculation pumps which are operated continuously may help to alleviate the scum problem. In other cases, it may be feasible to install digester mixers of either the mechanical or the gas-mixed type. In cases where fixed cover digesters are provided, scum formations may often be broken up by the simple installation of high velocity nozzles through which warm supernatant liquid is continuously pumped. The nozzles are so installed so as to direct a high velocity spray downwards onto the scum layer. The action of the nozzles tends to break up the scum layer and cause it to sink.

(9) mechanical equipment. All mechanical equipment associated with digesters should be operated and maintained in strict accordance with the manufacturer's instructions. Particular attention must be paid to lubrication of the equipment because of the sometimes very gritty nature of the sludge which is pumped. Hot water or steam boilers if utilized should be inspected as required by the appropriate state agency and repairs, if necessary, should be made immediately. Since anaerobic digestion produces highly flammable gas (methane) which under certain conditions can be very explosive, good operating habits dictate the complete absence of all open flame or electrical equipment which is likely to cause sparks from digester control houses. Gas vents and other gas equipment should always be provided with flame traps and flame propogation checks. Occasionally such equipment installed in gas lines will become plugged by digester foaming. If such plugging occurs, the equipment should be immediately cleaned or replaced. The operation of any portions of the digester gas system after any gas safety equipment has been removed is extremely dangerous and should be avoided at all times.

(10) digestion tanks. Digestion tanks require cleaning on a periodic basis depending upon rate at which grit accumulates in digesters. If very effective grit removal is practiced at a treatment plant, it is conceivable that digesters may be operated as long as 10 or 15 years without ever requiring cleaning. However, if grit removal is not absolutely effective there is every likelihood that grit accumulations will slowly build up in digestion tanks. It is difficult to determine without dewatering the tank just how fast grit accumulations are building up. Normally the only indication that an operator has grit problems is when sludge withdrawal lines become plugged with grit. If rodding of the with-



FLAME ARRESTER
Figure (7-8)

drawal lines and backflushing either with air or high pressure water does not eliminate the stoppage, the only recourse is to dewater the digestion tank and clean it. Whenever possible, the contents of digesters to be dewatered should be placed either into another digester or into sludge lagoons or drying beds. If the contents are to be transferred into another digester, care must be taken not to pump grit from one digester into another and thus compound the problem.

(11) operation troubles. A few of the more common digester operating problems are listed below as follows:

a. temperature fluctuations. Pumping of large volumes of thin sludge at a high rate to a digester tends to cool it rapidly. Pumping sludge at a slower rate over a longer period of time will reduce the heat requirements and allow the digester heating system to more adequately cope with the incoming load. As previously stated, the best method of feeding a digester is to provide automatic time clock control on sludge pumps such that sludge is pumped for a few minutes out of each hour.

b. temperature drop in digesters equipped with internal heat exchangers. Over long periods of time, particularly if heating water temperatures exceed 130 degrees Fahrenheit, sludge solids may adhere to heating coils or internal heat exchangers within digesters. This sludge cake forms an insulating layer which prevents the transfer of heat to the contents of the digester. If such an insulating layer has formed on internal heat exchangers, the only possible remedy is to dewater the tank and clean the accumulated sludge cake from the internal heat exchanger. In other cases, heat transfer from internal heat exchangers may be insufficient because of poor velocities within the digester contents past the heat exchanger. If the digester is equipped with mixing devices, the speeding up of these devices or their operation on a continuous basis may serve to effectively increase the heat transfer rate.

c. gas production drops in spite of proper temperature conditions. Several conditions either singly or in combination may cause gradual reduction in gas production. Some of the more common are increasing accumulation of scum, increasing accumulation of grit, and excessive acid production or low pH conditions within digester contents. Remedies for excessive scum production and for excessive grit accumulations have already been discussed. Excessive acid production or low pH conditions within a digester, usually are indicative of overloading of the digester, introduction of acid wastes into the digester or the introduction of toxic materials into the digester. Organic overloads to digesters can sometimes be controlled by more effective control of sludge pumping or by eliminating or reducing shock industrial waste loads to the treatment plant. Usually the treatment plant operator has very little control over the amount of sludge which is produced, and in many cases, the only effective remedy is the addition of more digestion capacity. The determination of whether or not toxic materials are being fed to the digester is usually beyond the scope of the operator's capabilities; and if all other control measures fail, the operator may be well advised to seek engineering assistance to determine whether or not toxic elements are responsible for improper digester operation.

d. foaming. This condition characterizes an aggravated state of incomplete digestion. It is indicative of the lack of balance between additions of raw and reasonably digested sludge. It may be caused by a combination of any or all of the following. An insufficient amount of well-buffered sludge in the digester, excessive additions of raw sludge, particularly when sludge has a high volatile content, poor mixing of digester contents, temperature too low for prolonged periods followed by a rise in temperature of digester contents, withdrawal of too much digested sludge and excessive scum formations or grit accumulations reduce the effective capacity for digestion.

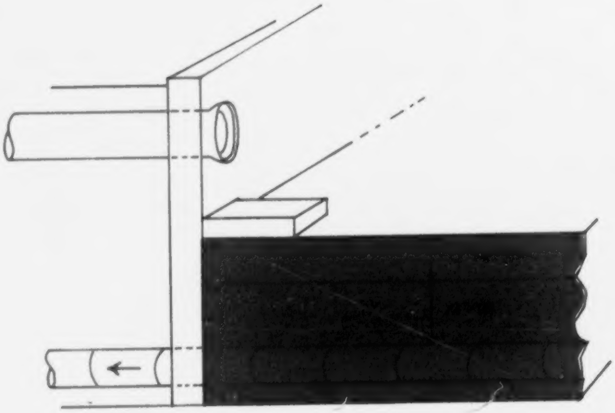
If foaming occurs, one or all of the following steps may help to control the situation: Temporarily reduce or stop raw sludge additions to the digester exhibiting foaming conditions. Add lime to keep the pH of the foaming digester between 6.8 and 7.2 while other corrective measures are taken. Restore good mixing within the digester. Raise the temperature to the normal range. Break up and remove excessive scum layers. If large quantities of oil or grit are present, it may be necessary to empty the digester and clean it. This may also be necessary if internal heat exchangers are heavily encrusted with sludge cake. As conditions improve, as indicated by restoration of normal pH conditions, volatile acids contents of less than 1,000 milligrams per liter and more normal gas production characteristics, raw sewage solids should again be added in small amounts at frequent intervals and slowly increased until digestion is once again brought into full production.

J. Aerobic Sludge Digestion Units. Aerobic sludge digestion units function in much the same way as do activated sludge plants except that the only influent to an aerobic sludge digester is sludge which has been removed either from primary or secondary sedimentation basins. Operation of aerobic sludge digesters is quite simple and usually it is only necessary to maintain adequate mixing and adequate concentrations of dissolved oxygen in the range of from 1.0 to 1.5 milligrams per liter. Either mechanical aerators or diffused air equipment may be utilized to provide both mixing and dissolved oxygen. Operation and maintenance of these units has been previously described. Aerobic sludge digesters are usually unheated since heating of their contents would result in a tremendous decrease in the solubility of dissolved oxygen and an accompanying increase in the oxygen demand by the biological organisms responsible for treatment. Usually aerobic sludge digesters are operated with theoretical detention times in a range of from 20 to 30 days and the entire contents of the digesters are kept mixed at all times. With this system, sludge is removed continuously from the digester at the same rate at which liquid is pumped into the unit.

Aerobically digested sludge usually exhibits good dewatering characteristics and it is often possible to apply the aerobically digested sludge directly to sand drying beds for dewatering without the necessity of concentrating the solids prior to application to drying beds. Aerobically digested sludge may also be lagooned.

K. Digested Sludge Disposal. Even the best, most concentrated sludge from either anaerobic or aerobic digestion systems contains too much water to permit satisfactory and economic disposal. For this reason, unless sludge is hauled from treatment works in the liquid form, additional treatment is usually given to further dewater the sludge before ultimate disposal.

(1) sludge drying beds. Sludge drying beds consist of a layer of graded gravel approximately 12-18 inches deep under a layer of clean sand 6 to 12 inches deep. Open joint tile underdrains are usually laid in the gravel layer with at least 12-inch gravel cover and are spaced not more than 20 feet apart. The drying beds may be open to the weather or covered with a glass greenhouse type cover. Open sand drying beds are much more common. The drying of sludge on sand beds is a combination of two factors; first, drainage; and second, evaporation. When sludge is applied, the release of entrained and dissolved gases tend to float the solids leaving a layer of liquid at the bottom which drains away through the sand. Gas release may be increased by dosing the sludge with alum (in some cases). A dosage of one pound of alum to approximately 200 gallons of sludge is common. The major portion of drainage occurs in the first 12 to 18 hours. Further drying is due to evaporation of water. As evaporation takes place, the sludge layer cracks open at the surface permitting further evaporation from lower layers.



SLUDGE DRYING BEDS
Figure (7-9)

The sludge should be applied to drying beds as dense as possible. Experience is the best guide in determining the depth of sludge to be applied. It generally ranges from 8 to 12 inches. The condition and moisture content of the sludge, the sand bed area available, and the need for storage space in digesters are factors to consider. A thinner layer will dry more rapidly permitting quick removal and reuse of the bed. An 8-inch layer should dry in about 3 weeks assuming that significant precipitation on open beds does not occur. A 10-inch layer of the same sludge will take 4 weeks so that the 25 percent more sludge actually takes 30 percent more time. From these observations it appears advantageous to withdraw as thin a layer of digested sludge as possible onto drying beds. The surface of sand drying beds should be kept clean and free from all previously discharged sludge. Never discharge wet sludge on dried or partially dried sludge since the underlying layer of sludge, for practical purposes, will never dry.

After sludge has been drawn from a digester, sludge lines should be well drained and flushed with water. This not only prevents plugging of the lines but also eliminates the possibility of excessive gas pressures being generated in closed lines. Sludge lines from digesters to sludge drying beds should always be sloped to drain, so that freezing of liquid in the sludge lines can be avoided.

The best time to remove dried sludge from drying beds depends on a number of factors such as subsequent treatment by grinding or shredding, the need to remove additional sludge from digesters and, of course, the moisture content of the sludge on the beds. Sludge can be removed by shovel or forks at a moisture content of 60 to 70 percent, but if it is allowed to dry to 40 percent moisture, it will weigh only half as much. At the other end of the scale a dried sludge with 10 percent moisture is extremely dusty, crumbles quite readily and is difficult to remove from the drying beds. Many operators of smaller treatment plants use wheelbarrows to haul sludge from drying beds. Planks are often laid on the bed for a runway so that the wheelbarrow tire does not sink into the loose sand of the bed. Wheelbarrows can be placed close to the worker so that the shoveling distance is not great. Most plants use pickup trucks or dump trucks to load dried sludge and transport the loaded material from the drying bed. Dump trucks have the advantage of quick unloading and most municipalities have dump trucks which may be utilized for this purpose. Where trucks are used, it is best to have concrete treadways in the sludge drying bed wide enough to carry the dual wheels since the drying bed can be damaged if the trucks are driven directly on the sand. The treadways should be spaced close enough together so that there is not a long carry from any part of the drying bed to the truck. If permanent treadways are not provided, heavy planks may be placed on the sand.

After sludge has been removed, drying beds should be prepared for the next application of sludge. It may be necessary to replace sand which has been lost by previous cleanings. About an inch of sand is lost each year so that the sand layers should be built up to a proper depth about once every 3 years. Any clean coarse sand is satisfactory. If beds are kept idle for long periods they should be kept free from excessive weed growths.

(2) sludge lagoons. Considerable labor involved in sludge drying bed operation may be avoided by the use of sludge lagoons. These lagoons are excavated areas in which digested sludge is allowed to drain and dry over a period of months or even years. They are usually dug out by bulldozers or other moving equipment with the excavated material used for building up the sides to confine the sludge. Depths may range from 2 to 6 feet. Underdrain systems are usually not provided. Digested sludge is drawn into the lagoons as frequently as needed with successive drawings on top of the previous ones until the lagoon is filled. A second lagoon may then be operated while the first one is drying. After the sludge has dried enough to be moved, a bulldozer or front end loader may be used to scoop out the dewatered sludge. Lagoons may be used for regular drying of sludge and reused after emptying or allowed to fill and dry and then leveled and developed into lawns. They can also be used as emergency storage when sand drying beds are full or when digesters must be emptied for repair. In the latter case, partially digested sludge should be treated with some odor control chemical such as hydrated or chlorinated lime prior to discharge into sludge lagoons.

(3) chemical conditioning. Chemical conditioning (sludge conditioning) prepares sludge for better and more economical filter treatment with vacuum filters or centrifuges, as previously discussed. Many chemicals have been used such as sulfuric acid, alum, chlorinated coppers, ferrous sulfate, ferric chloride with or without lime and others. The local cost of the various chemicals is usually the determining factor. Ferric chloride and lime are generally found to be the most economical chemicals to use in the Pacific Northwest area. Amounts of sludge conditioning chemicals required vary from plant to plant; however, where ferric chloride and lime are used, most plants are able to obtain fairly good sludge conditioning using ferric chloride dosages of from 6 to 10 pounds of ferric chloride per ton of dry solids and lime dosages of from 15 to 20 pounds of lime per ton of dry solids.

(4) mechanical dewatering of conditioned sludge. Where vacuum filters or centrifuges are used to dewater digested sludge, the manufacturer's operating instructions should be strictly followed with regard to the operation and maintenance of the equipment.

(5) heat drying or incineration of sludge. The description of operating and maintenance procedures associated with heat drying or incineration of sludge are beyond the scope of this operator's manual. For plants so equipped it is suggested that operators consult the equipment manufacturer's recommendation concerning the operation of this equipment.

(6) liquid sludge disposal. Where sludge is disposed of in the liquid form by means of tank truck, operators should be fully cognizant of the regulations of the Pollution Control Commission. In particular, liquid sludge should never be applied to fields which are used for growing edible root crops such as carrots, beets, or potatoes. The use of either dried or liquid digested sludge as a fertilizer for crops intended for human consumption is expressly prohibited in the State of Washington unless written approval is obtained from the State Director of Health.

OPERATION, TESTING AND CONTROL

1. **General.** As has been previously discussed, laboratory tests give forewarning of possible breakdowns or failures in treatment processes or indicate necessary corrective measures. They also serve to show the efficiency of the plant, that is, whether or not the plant is doing the job for which it has been designed.

Logically, the larger plants should provide for more complete control because of their greater potential in creating a pollution condition and because of the greater investment represented. Also, in plants providing a high degree of treatment, more complete control is indicated because of the complexity of the processes and the importance of efficient operation to protect downstream water users. These factors have been taken into consideration in determining the following testing scheduled. Note that the sampling point and frequency is listed for each test.

Procedures and necessary laboratory equipment and reagents for each of the tests listed are given in Chapter 8 of this manual. In addition to the information contained in this manual, operators of all sewage treatment plants at which any laboratory testing is performed should have available a copy of Standard Methods for the Examination of Water and Waste Water. This manual is a joint publication of the American Public Health Association, The American Waterworks Association, and the Water Pollution Control Federation. Copies may be obtained from the Water Pollution Control Federation, 3900 Wisconsin Avenue, Washington D. C. and are priced at $12 per copy to members of the organization if payment is submitted with the order.

2. **Imhoff Tanks or Clarigesters.**

Tests	Sampling Points	Frequency
pH	Raw Sewage	Daily
	Final Effluent	Daily
	2' Above Sludge Blanket	Weekly
Settleable Solids	Raw Sewage	Daily
	Final Effluent	Daily
Chlorine Residual	Final Effluent	Daily
Relative Stability	Final Effluent	Daily
Flow	Influent or Effluent	Daily

3. **"Package" Aeration Plants – Serving Less than 1,000.**

Tests	Sampling Points	Frequency
pH	Raw Sewage	Daily
	Final Effluent	Daily
Settleable Solids	Raw Sewage	Daily
	Final Effluent	Daily
Settleability	Mixed Liquor	Daily
Chlorine Residual	Final Effluent	Daily
Relative Stability	Final Effluent	Daily
Flow	Influent or Effluent	Daily

4. **Primary Plants – Serving Less than 5,000 Persons.**

Tests	Sampling Points	Frequency
Temperature	Raw Sewage	Daily
	Digester(s)	Daily

pH	Raw Sewage	Daily
	Final Effluent	Daily
	Digester(s)	Daily
Flow	Influent or Effluent	Daily
Chlorine Residual	Final Effluent	Daily
DO	Raw Sewage	Daily
	Final Effluent	Daily
Relative Stability	Final Effluent	Weekly
Settleable Solids	Raw Sewage	Daily
	Final Effluent	Daily
Suspended Solids	Raw Sewage	Monthly
	Final Effluent	Monthly
Total Solids (2)	Raw Sludge	Monthly
	Digested Sludge	Monthly
Vol. Solids (2)	Raw Sludge	Weekly
	Digested Sludge	Weekly
Gas Anal. (6) & Vol. (2,3)	Primary Digester	Daily
Alk. (3)	Supernatant	Weekly
Volatile Acids (3)	Primary Digester	Twice Monthly

5. Primary Plants – Serving 5,000 to 100,000 Persons.

Tests	**Sampling Points**	**Frequency**
Temperature	Raw Sewage	Daily
	Digester(s)	Daily
pH	Raw Sewage	Daily
	Final Effluent	Daily
	Clarifier Effluent(s)	Daily
	Digester(s)	Daily
Flow	Influent or Effluent	Daily
Chlorine Residual	Final Effluent	Daily
DO	Raw Sewage	Daily
	Final Effluent	Daily
	Clarifier Effluent(s)	Daily
BOD	Raw Sewage	Twice Monthly
	Final Effluent	Twice Monthly
Settleable Solids	Raw Sewage	Daily
	Final Effluent	Daily
Suspended Solids	Raw Sewage	Monthly
Total Solids (2)	Final Effluent	Monthly
	Raw Sludge	Monthly
Vol. Solids (2)	Primary Sludge	Monthly
	Secondary Sludge	Monthly
Gas Anal. (6) & Vol. (2)	Raw Sludge	Weekly
Alk.	Primary Sludge	Weekly
	Secondary Sludge	Weekly
Vol. Acids	Primary Digester	Daily
	Primary Supernatant	Weekly
	Secondary Supernatant	Weekly
	Primary Supernatant	Weekly

6. Primary Plants–Serving Over 100,000 Persons.

Tests	**Sampling Points**	**Frequency**
Temperture	Raw Sewage	Daily
	Digester(s)	Daily
pH	Raw Sewage	Daily
	Final Effluent	Daily
	Clarifier Effluent(s)	Daily
	Digester(s)	Daily

Flow	Influent or Effluent	Daily
Chlorine Residual	Final Effluent	Daily
DO	Raw Sewage	Daily
	Final Effluent	Daily
	Clarifier Effluent(s)	Daily
BOD	Raw Sewage	Weekly
	Final Effluent	Weekly
Settleable Solids	Raw Sewage	Daily
	Final Effluent	Daily
Suspended Solids	Raw Sewage	Twice Monthly
	Final Effluent	Twice Monthly
Total Solids	Raw Sludge	Twice Monthly
	Primary Sludge	Twice Monthly
	Secondary Sludge	Twice Monthly
Vol. Solids	Raw Sludge	Weekly
	Primary Sludge	Weekly
	Secondary Sludge	Weekly
Gas Anal. (6) & Vol.	Primary Digester	Daily
Alk.	Primary Supernatant	Weekly
	Secondary Supernatant	Weekly
Vol. Acids	Primary Supernatant	Weekly
	Secondary Supernatant	Weekly

7. Single State Filtration Plants — Serving Less than 5,000 Persons.

Tests	**Sampling Points**	**Frequency**
Temperature	Raw Sewage	Daily
	Digester(s)	Daily
pH	Raw Sewage	Daily
	Final Effluent	Daily
	Primary Effluent	Daily
	Filter Effluent	Daily
	Digester(s)	Daily
Flow	Influent or Effluent	Daily
Chlorine Residual	Final Effluent	Daily
DO	Raw Sewage	Daily
	Final Effluent	Daily
	Primary Effluent	Daily
	Filter Effluent	Daily
Relative Stability	Final Effluent	Weekly
Settleable Solids	Raw Sewage	Daily
	Final Effluent	Daily
	Primary Effluent	Daily
	Filter Effluent	Daily
Suspended Solids	Raw Sewage	Monthly
	Final Effluent	Monthly
Total Solids (2)	Raw Sludge	Monthly
	Digested Sludge	Monthly
Vol. Solids (2)	Raw Sludge	Weekly
	Digested Sludge	Weekly
Gas Anal. (6) & Vol. (2,3)	Primary Digester	Daily
Alk. (3)	Supernatant	Weekly
Vol. Acids	Primary Digester	Twice Monthly

8. Single Stage Filtration Plants — Serving. 5,000 to 20,000 Persons.

Tests	**Sampling Points**	**Frequency**
Temperature	Raw Sewage	Daily
	Digester(s)	Daily
pH	Raw Sewage	Daily
	Final Effluent	Daily

	Primary Effluent	Daily
	Filter Effluent	Daily
	Digester(s)	Daily
Flow	Influent or Effluent	Daily
Chlorine Residual	Final Effluent	Daily
DO	Raw Sewage	Daily
	Final Effluent	Daily
	Primary Effluent	Daily
	Filter Effluent	Daily
BOD	Raw Sewage	Monthly
	Final Effluent	Monthly
	Clarifier Effluent(s)	Monthly
Settleable Solids	Raw Sewage	Daily
	Final Effluent	Daily
	Primary Effluent	Daily
	Filter Effluent	Daily
Suspended Solids	Raw Sewage	Monthly
	Final Effluent	Monthly
Vol. Solids (2)	Raw Sludge	Weekly
	Digested Sludge	Weekly
Gas Anal. (6) & Vol. (2)	Primary Digester	Daily
Alk.	Primary Supernatant	Weekly
	Secondary Supernatant	Weekly
Vol. Acids	Primary Supernatant	Twice Monthly
	Secondary Supernatant	Twice Monthly

9. Single Stage Filtration Plants – Serving Over 20,000 Persons.

Tests	Sampling Points	Frequency
Temperature	Raw Sewage	Daily
	Digester(s)	Daily
pH	Raw Sewage	Daily
	Final Effluent	Daily
	Primary Effluent	Daily
	Filter Effluent	Daily
	Digester(s)	Daily
Flow	Influent or Effluent	Daily
Chlorine Residual	Final Effluent	Daily
DO	Raw Sewage	Daily
	Final Effluent	Daily
	Primary Effluent	Daily
	Filter Effluent	Daily
BOD	Raw Sewage	Twice Monthly
	Final Effluent	Twice Monthly
	Primary Effluent	Twice Monthly
Settleable Solids	Raw Sewage	Daily
	Final Effluent	Daily
	Primary Effluent	Daily
	Filter Effluent	Daily
Suspended Solids	Raw Sewage	Monthly
	Final Effluent	Monthly
	Primary Effluent	Monthly
Total Solids	Raw Sludge	Monthly
	Primary Sludge	Monthly
	Secondary Sludge	Monthly
Vol. Solids	Raw Sludge	Weekly
	Primary Sludge	Weekly
	Secondary Sludge	Weekly
Gas Anal. (6) & Vol.	Primary Digester	Daily
Alk.	Primary Supernatant	Weekly

	Secondary Supernatant	Weekly
Vol. Acids	Primary Supernatant	Twice Monthly
	Secondary Supernatant	Twice Monthly

10. Two Stage Filtration Plants – Serving Less than 20,000 Persons.

Tests	**Sampling Points**	**Frequency**
Temperature	Raw Sewage	Daily
	Digester(s)	Daily
pH	Raw Sewage	Daily
	Final Effluent	Daily
	Primary Effluent	Daily
	Intermediate Effluent	Daily
	Digester(s)	Daily
Flow	Influent or Effluent	Daily
Chlorine Residual	Final Effluent	Daily
DO	Raw Sewage	Daily
	Final Effluent	Daily
	Primary Effluent	Daily
	Intermediate Effluent	Daily
	Primary Filter Effluent	Daily
	Secondary Filter Effluent	Daily
BOD	Raw Sewage	Monthly
	Final Effluent	Monthly
	Primary Effluent	Monthly
	Intermediate Effluent	Monthly
Settleable Solids	Raw Sewage	Daily
	Final Effluent	Daily
	Primary Effluent	Daily
	Intermediate Effluent	Daily
Suspended Solids	Raw Sewage	Monthly
	Final Effluent	Monthly
	Primary Effluent	Monthly
	Intermediate Effluent	Monthly
Total Solids	Raw Sludge	Monthly
	Primary Sludge	Monthly
	Secondary Sludge	Monthly
Vol. Solids	Raw Sludge	Monthly
	Primary Sludge	Monthly
	Secondary Sludge	Monthly
Gas Anal. (6) & Vol. (2,3)	Primary Digester	Daily
Alk. (3)	Primary Supernatant	Weekly
	Secondary Supernatant	Weekly
Vol. Acids (3)	Primary Supernatant	Twice Monthly
	Secondary Supernatant	Twice Monthly

11. Two Stage Filtration Plants – Serving Over 20,000 Persons.

Tests	**Sampling Points**	**Frequency**
Temperature	Raw Sewage	Daily
	Digester(s)	Daily
pH	Raw Sewage	Daily
	Final Effluent	Daily
	Primary Effluent	Daily
	Intermediate Effluent	Daily
	Digester(s)	Daily
Flow	Influent or Effluent	Daily
Chlorine Residual	Final Effluent	Daily
DO	Raw Sewage	Daily
	Final Effluent	Daily

	Primary Effluent	Daily
	Intermediate Effluent	Daily
	Secondary Filter Effluent	Daily
BOD	Raw Sewage	Twice Monthly
	Final Effluent	Twice Monthly
	Primary Effluent	Twice Monthly
	Intermediate Effluent	Twice Monthly
Settleable Solids	Raw Sewage	Daily
	Final Effluent	Daily
	Primary Effluent	Daily
	Intermediate Effluent	Daily
Suspended Solids	Raw Sewage	Monthly
	Final Effluent	Monthly
	Primary Effluent	Monthly
	Intermediate Effluent	Monthly
Total Solids	Raw Sludge	Monthly
	Primary Sludge	Monthly
	Secondary Sludge	Monthly
Vol. Solids	Raw Sludge	Monthly
	Primary Sludge	Monthly
	Secondary Sludge	Monthly
Gas Anal.(6) & Vol.	Primary Digester	Daily
Alk.	Primary Supernatant	Weekly
	Secondary Supernatant	Weekly
Vol. Acids	Primary Supernatant	Twice Monthly
	Secondary Supernatant	Twice Monthly

12. Activated Sludge Plants – Serving Less than 20,000 Persons.(1)

Tests	Sampling Points	Frequency
Temperature	Raw Sewage	Daily
	Digester(s)	Daily
pH	Raw Sewage	Daily
	Final Effluent	Daily
	Primary Effluent	Daily
	Digester(s)	Daily
Flow	Influent or Effluent	Daily
Chlorine Residual	Final Effluent	Daily
DO	Raw Sewage	Daily
	Final Effluent	Daily
	Primary Effluent	Daily
	Aerators	Daily
BOD	Raw Sewage	Monthly
	Final Effluent	Monthly
	Primary Effluent	Weekly
Settleable Solids	Raw Sewage	Daily
	Final Effluent	Daily
	Primary Effluent	Daily
Suspended Solids	Raw Sewage	Monthly
	Final Effluent	Monthly
	Primary Effluent	Monthly
	Aerators	Weekly
Volatile Susp. Solids	Aerators	Weekly
Total Solids (2)	Raw Sludge	Monthly
	Digested Sludge	Monthly
Vol. Solids (2)	Raw Sludge	Monthly
	Digested Sludge	Monthly
Gas Anal. (6) & Vol. (2,3)	Primary Digester	Daily
SVI	Aerators	Weekly
Loading Index	Aerators	Weekly

Alk. (3)	Primary Supernatant	Weekly
	Secondary Supernatant	Weekly
Vol. Acids (3)	Primary Supernatant	Twice Monthly
	Secondary Supernatant	Twice Monthly

13. Activated Sludge Plants – Serving Over 20,000 Persons.

Tests	Sampling Points	Frequency
Temperature	Raw Sewage	Daily
	Digester(s)	Daily
pH	Raw Sewage	Daily
	Final Effluent	Daily
	Primary Effluent	Daily
	Aerators	Daily
	Digester(s)	Daily
Flow	Influent or Effluent	Daily
Chlorine Residual	Final Effluent	Daily
DO	Raw Sewage	Daily
	Final Effluent	Daily
	Primary Effluent	Daily
	Aerators	Daily
BOD	Raw Sewage	Twice Monthly
	Final Effluent	Twice Monthly
	Primary Effluent	Daily
Settleable Solids	Raw Sewage	Daily
	Final Effluent	Daily
	Primary Effluent	Daily
Suspended Solids	Raw Sewage	Monthly
	Final Effluent	Monthly
	Primary Effluent	Monthly
	Aerators	Daily
Volatile Susp. Solids	Aerators	Daily
Total Solids	Raw Sludge	Monthly
	Digested Sludge	Monthly
Vol. Solids	Raw Sludge	Monthly
	Digested Sludge	Monthly
Gas Anal. (6) & Vol.	Primary Digester	Daily
SVI	Aerators	Daily
Alk.	Primary Supernatant	Weekly
	Secondary Supernatant	Weekly
Vol. Acids	Primary Supernatant	Twice Monthly
	Secondary Supernatant	Twice Monthly
Loading Index	Aerator	Daily

14. Sewage Lagoons – Serving Less than 5,000 Persons.(1)

Tests	Sampling Points	Frequency
Temperature	Individual Cells	Daily
pH	Individual Cells	Daily
Flow	Influent or Effluent	Daily
Chlorine Residual	Final Effluent	Daily
DO	Raw Sewage (5)	Twice Weekly
Relative Stability	Final Effluent	Weekly
Settleable Solids	Raw Sewage	Daily
	Final Effluent	Daily

15. Sewage Lagoons – Serving Over 5,000 Persons.

Tests	Sampling Points	Frequency
Temperature	Individual Cells	Daily
pH	Raw Sewage	Daily

	Final Effluent	Daily
Flow	Influent or Effluent	Daily
Chlorine Residual	Final Effluent	Daily
DO	Raw Sewage	Twice Weekly
	Final Effluent	Twice Weekly
	Individual Cells	Twice Weekly
BOD	Raw Sewage	Monthly
	Final Effluent	Monthly
Settleable Solids	Raw Sewage	Daily
	Final Effluent	Daily

16. **Non-Overflow Lagoons** are exempt from the above testing schedule. They require regular inspection. Visual reports should be submitted monthly to the District Engineers of the State Health Department and Pollution Control Commission indicating climatic conditions, lagoon conditions, maintenance procedures, etc.

17. **Modifications**
    1) Uncommon treatment processes or equipment such as bio-activation, vacuators, vacuum filters, pre-aeration units, etc., will require special consideration.
    2) Plants having heavy industrial waste loads may require special consideration.
    3) At plants with unheated digesters total and volatile solids may be omitted.
    4) Diffused air plants will, in general, follow the testing schedule and frequency of mechanically activated sludge plants, but may require additional consideration.

18. **Footnotes**:
    1) For plants serving less than 300, contact Pollution Control Commission or State Health Department.
    2) Omit for unheated digesters.
    3) Omit for plants under 1000.
    4) Aerators—daily.
    5) During odor season.
    6) For digesters in which problems are reasonably expected this test may be an invaluable aid. It is recommended that this test be used as a regular control test. Optional.

MAINTENANCE OF TREATMENT EQUIPMENT

1. Buildings and Structures.

A. Paint and Protective Coatings. The importance of a regular program of painting and application of other protective coatings at all waste treatment plants cannot be over-emphasized. Paints and other coatings provide a pleasing appearance for the entire plant; however, their most valuable asset is the protection of structures and equipment from corrosion or deterioration, both from the weather and from the nature of the wastes being treated. Paints and protective coatings, when properly applied, return tremendous value for the small investment required in prolonging the useful life of any facility.

The scope of this operating manual is far too limited to allow a complete discussion of the use of and application of various paints and protective coatings; however, operators should be aware of the fact that the labor involved in application and preparation of surfaces to receive paints and protective coatings is far more costly than the actual investment in materials. For this reason, operators should always be suspicious of so-called bargain materials and should insist on the use of the best possible grades of materials when it becomes necessary to repaint various structures or equipment.

Another point frequently overlooked is that surface preparation is important if a satisfactory finished job is to result. The practice of applying paints over loose scale or rust or on greasy surfaces should be discouraged. This represents nothing more than a complete waste of time and material. A little time spent in rust removal, crack patching, wire brushing etc., will certainly result in a more serviceable job. Operators should also be cognizant of the fact that many of the newer paints and protective coatings may require specific undercoating materials in order to ensure good bonding or compatibility with existing paint systems. When in doubt, small trial sections should always be painted in order to ensure compatibility with underlying coatings. A good example of incompatibility can be found if factory asphalt coated cast iron pipe is painted with most types of presently used industrial enamels. Unless an intermediate coat is applied, operators will find that the asphalt coating will inevitably bleed through the newly applied enamels causing an unsatisfactory job. Most reputable paint suppliers or representatives are well equipped to answer questions which operators may have concerning the best types of materials to be used for various applications. It is suggested that these specialists be consulted for recommendations prior to undertaking painting or protective coating application programs.

B. Housekeeping. Just as a well-ordered home or business office usually indicates an efficient operation, so does a well-kept treatment plant usually indicate pride on the part of the operating staff as well as good and efficient operation. There are, of course, a multitude of spare parts, tools, records, and reference materials which need to be used from time to time during the normal routine operation of any treatment works. These items should be neatly stored and classified in a manner that permits immediate availability for use when needed.

Laboratories in particular should be kept as clean and well-ordered as is possible even though most of the equipment may be in more or less constant use. Operators should always strive to maintain their operating buildings in a condition which would not embarrass them should various city officials elect to pay a surprise visit to the plant.

C. Repair. Repairs should always be accomplished as quickly as is possible in order to minimize down-time of any particular pieces of equipment. Even though stand-by units may be provided, items that require repair should be placed back into operating condition as soon as possible. The tendency to neglect small necessary repairs often leads to the necessity for major repairs. The old time-worn adage, "An ounce of prevention is worth a pound of cure," is certainly applicable here.

2. **Grounds.**

A. Landscaping. Frequently, treatment plants are not provided with any type of overall landscaping plan at the time of their construction. Those plants which are located fairly close to residential neighborhoods should be landscaped as soon as is possible even though the overall program may need to be undertaken a little at a time. It is unnecessary to select extremely expensive and very choice shrubs for the purpose of landscaping treatment plants. Occasionally local nurseries are willing to make available less choice items at little or no cost. With a minimum amount of care and a little professional assistance obtained from local nurserymen or greenhousemen, operators can often develop very attractive landscaping layouts for their treatment plants. The condition of landscaping on any given treatment plant is always quite important to a visitor because it represents one of his first impressions of the plant. Community relations will certainly be improved if these first impressions are good.

It should be unnecessary to remind operators that lawns and grassed areas require periodic fertilization and a regular schedule of mowing during the growing season if they are to present a good appearance. In summary, lawns and landscaping at sewage treatment works are in no way different from that found in residential areas and about the same types and amount of care is required if a pleasing appearance is to result.

B. Road Repair. Access roads in the treatment plant area should be maintained in good condition at all times. Even if only graveled roads have been provided, the roads should be periodically bladed and reshaped as required in order to maintain a good wearing surface. Most municipalities have equipment available for this type of work and a little judicious "needling" of responsible officials in charge by the treatment plant operator will go a long way towards helping the operator obtain necessary help and equipment for this purpose. If dust is a problem around plants, it is often possible to obtain used oil which may be applied to the surface of the gravel roadway. The use of granular calcium chloride sprinkled over the surface of graveled roads also may be of some assistance. During periods of heavy traffic in and around plant sites, it may be at times necessary for operators to wet down the surface of the road in order to eliminate dust blowing onto nearby residential areas. Again, this is a matter of community relations and it is always advisable to maintain the best possible public relations program.

3. **Mechanical Equipment.**

A. General. In general, each piece of mechanical equipment supplied in any treatment works should be accompanied by descriptive literature provided by the equipment manufacturer. This descriptive literature usually indicates make, model, serial number, operating procedures, assembly and disassembly instructions, necessity for any special maintenance and how to accomplish necessary repairs. This information is extremely valuable and should be maintained in an up-to-date filing system. Unfortunately, there is a tendency for much of this descriptive literature to become lost or misplaced and as a result, many operators do not have such information available. Operators who are faced with this difficulty should evaluate all available information which they have at their disposal, set up a complete filing system and then write to all of the various equipment manufacturers requesting additional copies of descriptive literature. In most cases, such information will still be available and it can usually be obtained at no cost. In some cases, consulting engineers responsible for the original design of the treatment works, may also be able to assist with the obtaining of specific information or descriptive literature. Officials of the

Pollution Control Commission may also be helpful.

In addition to maintaining a file of all descriptive literature, most operators have found it advantageous to set up a system of files which indicates grease and lubrication requirements for various equipment. Often times a separate card is made for each piece of equipment requiring maintenance. This card indicates the frequency with which lubrication or other maintenance must be performed as well as other pertinent specialized information. In this manner, operators can ensure that needed lubrication or other maintenance will not be forgotten simply because there was no record of when the job was last done.

B. Electrical Switchgear. In most cases it is not advisable for plant operators to attempt repairs to electrical switchgear other than to replace fuses or individual circuit breakers as may be required. There is always an element of danger present when working on electrical switchgear and persons not qualified are well advised to seek the help of specialists if electrical problems develop. It is of prime importance to make certain that any electrical equipment which is to be either worked on or inspected is isolated from operating electrical circuits in a positive manner. In the event that specific electrically operated units are undergoing repair, it is always advisable to lock the individual starter or breaker unit in the "Off" position and to place a tag on the starter unit indicating that the starter or breaker is not to be tripped.

C. Lamps. Electric lights provided for the purpose of illumination or for the purpose of indicating various control functions should always be maintained in operating condition. All lamps should be tested and inspected regularly to ensure that they are in an operating condition and a supply of spare or extra lamps should be on hand in storage at the plant. It is of little value to have illuminated control panels if the indicator lights do not function properly since their real value is to indicate to an operator at a glance, which equipment items are in operation at any given time. It is often difficult to reach exterior lights or in some cases even interior lights provided for illumination purposes. In some cases, replacement of lighting fixtures may be warranted in order to make lamp replacement more convenient. In other cases, the use of long-life or industrially-rated lamps may make the frequency of lamp replacement much less.

D. Motors. When properly maintained and lubricated, most electric motors have an extremely long life even when operated on a continuous basis. Manufacturer's instructions should always be strictly followed with regard to lubrication and maintenance of electric motors. Operators should be alert to indications of possible troubles by occasionally checking temperatures and listening for unusual noises. If abnormal temperatures or unusual noises are encountered, it is good practice to take the particular unit exhibiting problems out of service as soon as is possible and inspect to determine the cause. One problem which operators may encounter at times is frequent operation of the thermal overload protectors commonly installed in magnetic starters for the electric motors. These devices act to limit the maximum current flow to a motor and open the circuit should appreciably greater than full load current be drawn by the motor involved. At times, operators have attempted to eliminate this problem by increasing the size of these overload current protectors which are commonly referred to as "heaters." This practice is much like replacing a blown fuse with a shorting contactor such as a coin in that it removes the protection provided by the overload device. In the event of any circuit failure this may subject the particular electric motor involved to higher than allowable currents. Operators who have a problem with starters that require frequent resetting should obtain the services of a qualified electrician in order to determine what the problem is rather than attempting to eliminate the problem by installing larger thermal overload devices. As a rule of thumb, overload devices protecting motors which have a service factor should be rated at not greater than 1.25 times the full load current as indicated on the motor nameplate. Overload devices protecting electric motors which do not have service factors such as totally enclosed motors should be rated at not greater than 1.15 times the full load current of the motor involved.

E. Pumps. Sewage pumps are perhaps the most important piece of equipment in any treatment plant. Normally a breakdown of pumping equipment means that sewage must be bypassed. A complete understanding of pump construction and operation is essential to provide proper maintenance. Periodic inspections should be made giving special attention to the following:

(1) bearings. Inspect for heat and noise and lubricate as recommended by the manufacturer.

(2) motors. Inspect for operating speed, unusual noises, high temperatures, and lubricate as recommended by the manufacturer.

(3) control equipment. Keep clean and free from moisture or corrosion. Maintain as recommended by the equipment manufacturer.

(4) pump operation. Inspect for vibra-

tion, unusual noises, and occasionally check for pumping rate.

(5) packing glands. Inspect for excessive leakage, tighten as required, inspect water seal system if such is provided, and generally maintain in accordance with manufacturer's directions.

Sewage is much more difficult to pump than water. The presence of grit and sand in sewage has an abrasive effect on pumps. Each object presents a problem in sewage pumping. Various types of pumps are used in sewage or sludge pumping applications. For raw waste pumping applications, the centrifugal type pump is most widely used. The only moving part of a centrifugal pump is the impeller rotating in a casing. The impeller is attached to a shaft and is supported by thrust bearings and one or more guide bearings depending on the length of the shaft. In submerged type pumps, the guide bearing or intermediate bearing cannot be a ball bearing construction since there is no way of keeping out sewage which would cause rust and corrosion. These bearings are normally sleeve type guide bearings made of bronze. The thrust bearing is usually a ball bearing located above the level of the sewage near the motor. Greasing of all bearings should be done in strict accordance with the manufacturer's instructions. Over-greasing should be avoided as too much grease will cause damage as fast as lack of lubrication.

The manufacturer's recommendations should be carefully followed in choosing packing for centrifugal pumps. A soft asbestos packing impregnated with graphite is commonly used if grease or water seals are not provided. The packing should be well lubricated since it increases the efficiency of the pump by reducing air leakage and prolongs the life of the packing and shaft by reducing friction. An external supply of clean water is the most effective lubricant and seal. Seal water should never be obtained by direct connection with a potable water supply because of the danger of cross connections. A separate seal water system should always be used. The pressure should be maintained greater than the operating head of the pump.

When water seal systems are used, never tighten a packing follower too tightly. A trickle of water should be provided to keep the gland cooled. A wrench is not desirable since tightening the nuts finger-tight is all that is required. If the packing box leaks excessively, remove the packing and repack with fresh packing. If the shaft is scored, the shaft must be replaced or the life of the packing will be shortened. Never repack with partly new and partly old packing, and when repacking be sure that the water seal ring is in proper position with the stuffing box to receive the seal water. A water seal serves a dual purpose in that as well as lubricating, it keeps gritty material from entering the packing box and thus increases the life of the packing and shaft.

The most common type of sludge pump is the plunger pump. It is the positive displacement type of pump which will pump mixtures of sludge, gas, and air as well as liquids. The packing should be tight enough to prevent leakage and to prevent air from being sucked into the cylinder. Too tight of packing will result in scored pistons, broken shear pins and even cracked cylinders. A liberal use of heavy oil around the packing will prolong the life of the packing and make it possible to keep the packing tight enough to prevent leakage. Ball valves must operate freely and should be replaced when worn. Never tighten the eccentric flange and eccentric body so tight that pins cannot shear should an overload occur. Manufacturer's instructions should be strictly followed in the selection of packing and lubricants to be used with plunger type pumps.

Other miscellaneous type of pumps commonly found in treatment works include the progressing cavity or Moyno type of pump and the torque flow (recessed impeller) type of centrifugal pump. Construction of the torque flow type of pump is very similar to that previously described for centrifugal pumps and lubrication and maintenance of packing and bearings is essentially the same.

Manufacturer's instructions should be strictly followed in the maintenance of Moyno pumps and in addition, operators should attempt to keep the grit content as low as possible since this type of pump is subject to rapid wear when pumping gritty slurries. Care must always be taken in the operation of a Moyno pump to ensure that the pump is not operated with a plugged suction. The operation of this pump depends on the lubricating effect of the liquid being pumped, and if operated in a dry condition damage can result quite rapidly to both locating and stationary parts of the pump.

F. Gear Drives. Gear drives should be inspected regularly and checked for excessive noise, vibration, and high temperatures. Manufacturer's instructions regarding lubrication should be strictly followed and oil should be changed as recommended. Only recommended shear pins should be used if such are provided on the output shaft since the use of improper shear pins may result in extensive damage to gears should overloads occur.

G. Chain Drives. Chain drives should be inspected regularly for signs of defective or worn links, and such links should be replaced as necessary. If the chain drive is designed to be lubricated,

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the manufacturer's instructions should be strictly followed. Large, slow moving chain drives such as those found on rectangular clarifiers are often designed to be non-lubricated or water-lubricated by immersion in the tank contents. These chains should also be inspected regularly for signs of wear and replacement should be made when necessary.

H. V-Belt Drives. V-belt drives usually require very little maintenance other than periodic checking in order to ensure that correct belt tension is maintained. It is occasionally advisable to apply a commercial belt dressing to the V-belts in order to prolong their life as well as assure quiet operation. Belt drives which are equipped with adjustable pulleys such as the U. S. Varidrive and the Reeves Rotodrive should not be constantly operated at any given speed. With this type of drive, it is advisable to at least weekly operate the belt drive over its entire speed range in order to assure trouble-free operation of the unit. It is also advisable to change the speed, even if only slightly, at least daily. If this is not done the adjustable pulleys tend to become sticky in their operation and the belt may actually tend to groove the adjustable pulley.

I. Scrapers. Scraper blades on sludge collectors should be inspected each time the sedimentation tank involved is dewatered. Circular clarifiers are usually equipped with brass squeegee blades. These blades are adjustable and should be adjusted to barely clear the bottom of the clarifier. Rectangular scrapers are usually constructed of selected redwood lumber and are equipped with a wearing shoe which rubs on steel rails installed in the bottom of the tanks. In most cases, the condition of rectangular scrapers may be observed as they travel along the top surface of the tank in order to perform the skimming operation. Broken wooden scraper blades should of course, be replaced immediately, it is advisable to occasionally check the wearing shoes provided on the blades in order to make certain they are not worn too badly.

J. Air Compressors. Air compressors should be lubricated in strict accordance with the manufacturer's instructions and in addition, the operator should pay particular attention to the maintenance of air filters if such are provided with the compressor. Many types of air filters are designed to be cleaned by the operator and as such are provided, the manufacturer's instructions should be strictly followed. In cases where the throw-away type air cleaners are provided, the operator should have on hand a supply of new filters so that the air filter may be replaced as required. Many air compressors are equipped with oil separators and with moisture separators. In particular, moisture separators should be drained of accumulated moisture at least daily and more often if required. Most air compressors are equipped with pressure switches which automatically start and stop the machine according to air pressure requirements. It is advisable to have a wide pressure range between "On" and "Off" operation of the compressor in order to minimize the number of compressor starts.

K. Boilers and Heat Exchangers. Boilers and heat exchangers should be maintained in a clean condition by periodic inspection and cleaning of sludge, water and fire tubes as required. The manufacturer's instructions and recommendations for cleaning of the equipment should be strictly followed. Boilers must be inspected on a regular basis. Electrical and gas safety equipment provided for boilers varies according to the equipment manufacturer; however, in all cases certain minimum safety requirements must be met. All safety equipment should be maintained in like-new condition; and in the event of failure of any part of the system, repairs should be made immediately. In many cases, particularly in small plants, repair of this type of equipment may be beyond the ability or training of the operator. In such cases expert assistance will be required. Operators should never attempt repairs on such items as motorized gas valves, electronic flame scanning equipment, fuel blending valves, and boiler controls unless they are completely familar with the equipment and are qualified to do the repair work. Because of the dangers of explosions, boilers should not be operated unless all safety equipment provided is in working condition.

L. Piping. Maintenance of piping usually consists of periodic painting and occasional cleaning, particularly in sludge lines. It may also be necessary occasionally to tighten flanges or replace gaskets in order to stop leakage. If it is necessary to change piping layouts, particular attention must be given to adequate and proper pipe supports. If flexible couplings are used, it may be necessary to provide thrust protection, particularly in cases where the pipes convey liquids under high pressures.

M. Valves. Many types of valves including gate valves and wafer type valves do not require lubrication. Maintenance on these valves usually consists of replacing worn packing and tightening followers in order to prevent leakage around the valve stems. The use of plug valves of both the lubricated and non-lubricated type, has become more and more prevalent, particularly in lines conveying sludge. If the lubricated type of valves are used, lubrication should be done in accordance with the manufacturer's instructions. It is advisable to operate all valves periodically by opening and closing them in order to assure that the valve will not stick in either the open or closed position. Many operators have found it advisable to paint the operating nuts of plug valves in such a way that the valve position that is either open or closed can be readily ascertained by looking at the valve. In some cases, valves are supplied which are never to be opened or closed except under emergency conditions. Such valves should always be equipped either with a chain and padlock or a sign indicating the nature of the valve operation so that unauthorized personnel will not operate the valves improperly.

N. Engines. Engines should be maintained in strict accordance with the manufacturer's recommendations and particular attention should be paid to lubrication and cooling requirements. Where gas-fired engines are used, all safety devices in the gas system must be maintained in proper working condition. Where gasoline or diesel fuel engines are used, operators need to pay particular attention to the fuel storage facilities so that the fuel supply does not become contaminated. It is advisable to clean fuel tanks periodically. Particular care must be taken when cleaning gasoline fuel storage tanks in order to prevent the possibility of explosion. Operators must never attempt to repair fuel storage tanks by welding or similar methods unless they are qualified to do this work and all necessary safety precautions have been observed.

Experience has shown that overspeed regulators can be a constant source of trouble with many types of engines commonly used in treatment plants. Operators should periodically check the operation of overspeed equipment in order to ensure that it will function properly to prevent engine run-away and resulting damage to the engine.

O. Generators. Where standby generation equipment is provided in treatment plants, the equipment should be operated periodically in order to assure that it will operate when needed. It is advisable to operate standby generators at least one hour per week for this purpose. Once started, engine generators should be allowed to run for a sufficient warm-up period. The electrical transfer switches should be checked by applying a load to the generator. Repairs to generators and associated engines should not be attempted by operators unless they are thoroughly qualified to make repairs or adjustments. When battery-powered starting equipment is provided for the engine generators, batteries should be maintained in a fully charged condition at all times. Batteries should be replaced when they become defective.

P. Laboratory Glassware and Equipment. Laboratory glassware and equipment should be maintained at all times in a clean condition, and the articles should be neatly stored either in drawers or on pegboards designed to hold the equipment. Laboratories themselves should be maintained in a clean condition so that the laboratory is ready for use at all times. Adequate supplies of various necessary chemicals should be kept on hand and these should be stored in accordance with the suppliers instructions. Many laboratory chemicals deteriorate in storage. Operators should buy these chemicals in small quantities and develop a system of ordering chemicals such that excessive waste does not occur.

Equipment such as laboratory balances should always be kept spotlessly clean and in a location free from excessive vibration. When not in use, the balance beam should be lifted off of the knife edges by use of the device provided on the balance. It is common practice to keep a small canister of desiccant or drying agent inside the case of laboratory balances. Anhydrous calcium chloride is the recommended desiccant for this purpose. In the event that repairs are required to precision laboratory equipment such as balances, the operator should contact the chemical supply house from which the equipment was purchased for assistance.

Items such as BOD incubators should be kept clean and in operating condition at all times. If a water bath system is used, it is advisable to keep a small amount of fungicide such as copper sulfate in the water bath in order to prevent the growth of slime organisms in the unit. In the event that the unit will be unused for extended periods of time, it is advisable to drain the units, wipe them thoroughly dry, and store them with the lid opened so as to ensure free circulation of air.

Q. Chlorinators and Appurtenances. Chlorinators should be maintained in a manner to prevent all chlorine leakage. Chlorine in the atmosphere is very corrosive and eventually destructive to chlorinator parts and electrical and mechanical equipment located near the chlorinator installation. The presence of a chlorine leak can be detected easily by its characteristic odor and can be located by an ammonia swab held near but not on a leaking part. Ammonia in the presence of chlorine produces a white vapor. Some metal plating is damaged by contact with the ammonia liquid. Even a small leak should be stopped and repaired as soon as detected. In the event of failure of the chlorinator itself, it is usually advisable to contact the equipment manufacturer in order to obtain assistance with repairs.

4. **Record Keeping.** Too much emphasis cannot be placed on record keeping. An operator, from a

review of such records, can determine the weaknesses of various pieces of equipment and will be able to determine which repair parts should be kept in stock. Such records may be kept on cards, i.e., one card for each piece of equipment. On these cards should be kept a record of regular periodic lubrication, inspections, cleaning and replacement of worn parts, and other data which is felt of importance to record. The date when the next regular servicing of equipment is scheduled should appear on the card where it can easily be seen. In some plants, in addition to the cards, a lubrication record should be kept. On this record the equipment is listed as well as the instructions for lubricating, including the type of oil suggested and the frequency of lubrication required. From this record the operator should be able to see when equipment should again be lubricated.

A very helpful scheme for planning preventive maintenance is to review the maintenance cards and set up ahead of time, lists of operations to be done on certain dates. If the plants and lists are small, the items can be entered in advance on a memo calendar pad. For larger plants the lists can be filed by date or code and simply noted ahead of time on a calendar. For any program to be successful, it must be accepted by the plant personnel. Sometimes this will make or break the entire program. The cards should be simple and instructions regarding the routine work to be done should be concise and clear. A typical equipment inspection and service record card is shown in Figure 7–10. Similar cards can, of course, be prepared for all different types of equipment in any treatment plant.

EQUIPMENT INSPECTION AND SERVICE RECORD
Worthington Raw Sewage Pump No. 3 Main Pump Room
Name Plate Data
(Enter here all data from Pump Name Plate)

Date	Work Done	Init.	Remarks
9-5-67	Installed 5 rings of new packing	JB	
9-18-67	Checked grease in upper & lower bearing	DB	
10-5-67	Lubricated magnetic drive	DB	
12-15-67	Removed impeller for inspection	JB	Pump not pumping at rating – Impeller badly worn
12-28-67	Installed new impeller	RT	
12-29-67	Adjusted packing to correct leaking	RT	
3-5-68	Checked grease in upper & lower bgs.	DB	
4-3-68	Lubricated motor	DB	
5-15-68	Replaced wearing rings	DM	
6-15-68	Installed 5 rings of new packing	JB	
6-28-68	Lubricated and checked magnetic drive	RT	

SERVICE RECORD

Date	Work Done	Init.	Remarks
7-2-68	Upper bearing noisy; reported to Supt.	JB	
8-3-68	Upper bearing flushed and added grease	RT	
8-15-68	Bearing still noisy. Replaced bearing	RT	
10-4-68	Lubricated motor	DB	

Figure 7–10
Typical Equipment Inspection & Service Record Card

RESPONSIBILITIES IN SEWAGE TREATMENT

In recent years there has been a great increase in public awareness of the importance of clean waters and of the necessity of protecting the nation's rivers, streams, lakes, and coastal and groundwaters against pollution. There has, in fact, been an ever increasing demand on the part of the public for more and cleaner water. Based on present conditions, it is safe to predict that this demand will continue to increase, rather than decrease, in the years that lie ahead.

As a result of this growing demand by the general public for more and cleaner water, there has been and will continue to be a corresponding increase in the responsibilities of all persons and agencies that are in any way concerned with or responsible for sewage treatment works, including their financing, construction, operation and maintenance.

The main responsibilities in sewage treatment naturally belong to the owners, the operators and the users of waste water disposal systems. Certain responsibilities, however, belong to or at least are shared by the designers, builders, regulatory agencies, and others.

1. **Responsibilities of the Owner.** The majority of sewage treatment works are publicly owned by cities, counties, special service districts, or other political entities. Regardless of whether the ownership is public or private, the responsibilities of the owner are substantially the same.

First of all, the owner must provide adequate financing both for construction and for operation and maintenance. Past experience has shown that in too many cases, not enough attention has been given to providing sufficient funds for this purpose. It does little good to install costly treatment works if they cannot be properly operated and maintained after they are built.

In the case of a municipally owned system the city council must assume the leadership and responsibility for promoting the approval and sale of the necessary bond issues, for levying sewer user charges and for developing other fiscal programs needed to build and operate the facilities.

Secondly, the owner must install facilities that will have adequate capacity to handle peak as well as average flows, both now and in the future; that will be capable of producing at all times the degree of treatment needed to protect the receiving waters; and that can be economically, efficiently and effectively operated and maintained. The consulting engineer who proposes and designs the facilities shares in these responsibilities.

In addition, the owner must employ a competent, well-trained operating staff. He must appreciate fully the necessity of proper operation and maintenance and should provide direction and leadership for the staff.

By ordinance, resolution or regulation the owner should exercise control over materials discharged into and uses made of each sewerage system. Such control is essential in order to prevent unnecessary damage to the system or interference with the treatment processes. Certain types of wastes should not be discharged into sewerage systems and certain others may require pretreatment before being discharged into such facilities. The owner has the responsibility of enforcing compliance with these important requirements.

2. **Responsibilities of the Operator.** In sewage treatment no one has more responsibility than does the operator. He must do everything within his power to provide adequate treatment at all times. He must equip himself by proper training and experience so that he can cope with all emergencies. He must understand and appreciate the need for maintaining a high degree of treatment and for protecting the quality of the receiving waters. He must practice preventive maintenance so that all mechanical equipment and treatment units will be kept continuously in the best possible operating conditions.

It is his responsibility to conduct certain laboratory and other tests which are needed as a guide for and proof of efficient and effective operation. He must maintain complete records of all tests and operating procedures for his own future guidance, for the protection of the owner, and for the information of the regulatory agency and the public.

An important responsibility of the operator is to keep the owner fully informed regarding anticipated future construction, operation and maintenance needs so that the necessary financing can be arranged and plans can be prepared ahead of time. Also, the operator must inform the owner and the state regulatory agency whenever an emergency arises which might result in greatly reduced treatment efficiency, plant shutdown, bypassing of raw sewage or other discharge of inadequately treated effluent to the receiving stream.

In addition the sewage treatment works operator also has the responsibility of keeping the local press and the public well informed about his job in order to develop their appreciation for and to obtain their full support of this most essential service.

3. **Responsibilities of the Users.** The users of sewage and waste collection and treatment systems have the responsibility for complying with the requirements established by the owner pertaining to the quantity and quality of wastes or materials that can or cannot be discharged into such facilities. The users also have the responsibility of paying their share of the cost of construction, operation and maintenance through property tax levies, connection fees or monthly sewer user charges. It is their responsibility to support proposals for sewerage extension projects that are needed to abate nuisance conditions and health hazards and to vote for bond issues proposed for financing new or improved treatment works that are needed.

Industrial users, in particular, have the responsibility for providing effective and adequate pretreatment where such is needed to comply with sewer-use ordinances and to prevent overloading or otherwise interfering with the efficiency of the sewage treatment works. Furthermore, industries which discharge large quantities of exceptionally strong wastes have the added responsibility of paying their fair share of the cost of construction and operation of the facilities needed to handle such pollution loads.

Whenever an industry is planning to enlarge or expand its operations, it must make sure that either the wastes from its enlarged plant will not overload the existing treatment works or that other arrangements will be made in advance for adequately handling the increased waste flow.

Whenever general obligation bonds or ad valorem tax levies are used to finance sewerage works construction or operation, all taxpayers within the taxing district, regardless of whether or not their properties are served by the system, must pay property taxes to help finance such facilities. This is on the premise that such facilities are necessary for the general welfare of the community or district and, therefore, should be paid for by all properties including those not presently directly benefited.

4. **Responsibilities of Regulatory Agencies and Others.** The states are generally recognized by federal statute (Public Law 84-660 as amended) and other laws as having the primary responsibility for water pollution control throughout the nation.

In Washington the official regulatory agency for water pollution control purposes is the Department of Ecology. It has the responsibility of promoting the installation of sewage and waste treatment works, of enforcing all laws of the state pertaining to water pollution control, of investigating complaints, making surveys, holding hearings and issuing orders, of adopting water quality standards for all public waters, of monitoring water quality conditions and collecting basic data, or reviewing and approving plans and specifications for all new or improved sewerage works projects constructed in the state, of assisting in the training and certification of sewage works operators, of supervising sewage plant operation, of establishing minimum sewage treatment and operation requirements, and of encouraging voluntary cooperation.

The Department of Ecology also has the responsibility of reviewing and approving applications and of assigning priorities for State and Federal grants to assist cities, counties and other political subdivisions to finance construction of sewage treatment works.

The Federal Government through the Environmental Protection Agency has the responsibility of enforcing all Federal laws pertaining to water pollution control; of sponsoring or conducting research, investigations and training; of developing comprehensive basin-wide programs for water pollution control; of approving water quality standards established by the states or promulgating its own water quality standards and enforcing the same for interstate streams; of assisting by means of Federal grants in the financing of (1) research and development, (2) state water pollution control programs and (3) the construction of local publicly-owned sewage treatment works; and of obtaining cooperation of all other Federal departments that operate sewerage and waste disposal facilities so that they will comply with the requirements of the Federal Water Pollution Control Act.

The state, county and city health departments have the responsibility of promoting the construction of public sewerage systems with approved treatment works in all areas in which domestic sewage cannot be disposed of in a safe manner by individual systems. In unincorporated areas this might require either the formation of a municipality, annexation to an existing city, or creation of a special service district, county service district or metropolitan service district.

If a county service district is formed, then the governing body of the county has the responsibility of installing, operating and maintaining the necessary sewerage works. In cities, this responsibility belongs to the city council and in special service or metropolitan districts to the board of directors.

CHAPTER VIII

SAMPLING AND TESTING

REASONS FOR SAMPLING

1. **Component Efficiency.** A sewage treatment plant is made up of several components which make up the total process. The measurement of influent quality and effluent quality can indicate operational problems, however sampling individual components identifies many intermediate problems much sooner. For example, if a digester were not working properly, the supernatant could become very strong and influence the overall efficiency of the treatment process. This situation could be avoided by sampling the digester and correcting a problem there before it affects the overall efficiency of the plant. A comparison can be made between the specified design efficiency and the actual operation efficiency of a component.

2. **Process Control.** In order to operate some processes efficiently, sampling and testing must be done, sometimes two or more times a day. An example is the chlorine residual test. The chlorine demand varies considerably during the day. In order to insure a low coliform bacteria count in the effluent, sufficient chlorine residual must be continually present. This residual can be followed by frequent testing and analysis.

Another example is an activated sludge plant. A favorable environment must be maintained for bacteria during their initial contact with the food (influent waste) and during their metabolism. Such variables as dissolved oxygen, mixed liquor suspended solids, and mixed liquor settleable solids are very critical in controlling the process and should be monitored closely.

3. **Monthly Reports for the State Regulatory Agency.** According to state law monthly sewage treatment plant operational reports must be submitted to the Department of Ecology. The information is used in the following ways:

> It indicates how well the sewage treatment plant is operating and provides some motivation to operate the plant as efficiently as possible. These data help the operator establish a reliable continued record of proof of performance. They help justify decisions, expenditures, and recommendations. Tests on the treated effluent from the plant are vital if a downstream water user someday claims in court that the treatment plant effluent has caused damage to his property or water supply.

Since the state regulatory agency samples the stream, a comparison between sewage treatment plant effluent and stream quality can be made. At larger sewage treatment plants, it is also a good idea to sample the receiving stream above and below the sewage treatment plant outfall.

The state agency reviews plans for sewer extensions. The monthly reports are used to determine if the sewage treatment plant can handle the proposed additional loading.

4. **Future Design Data.** When designing a sewage treatment plant expansion, an engineer is especially interested in how well the existing facilities work. Testing can show how each component works with an existing load. A record of the influent characteristics provides valuable information for the engineer in the design of a plant expansion.

The characteristics of the influent are especially important if significant industry loads are present. The designer is dependent upon the operator on tips for making improvements in the existing processes. A thinking operator can be of great help to a designing engineer.

5. **Industrial Waste Control.** All industries which are connected to a domestic sewerage system have to pay a sewer service charge. This charge should be based on the quantity and quality of their waste. The only way this can be determined is by sampling and testing their waste discharge to the sewer.

All sewage treatment plant owners should have industrial waste discharge ordinances. These ordinances limit the strength of the waste which can be discharged to the sewer. Effective ordinances require a continuing program of sampling and testing. It is extremely important that industries have adequate pretreatment and flow control so the sewage treatment plant will not be overloaded. A sampling manhole with a flow meter which totalizes and indicates peak flows might be used on the industrial sewer line before the industrial waste mixes with any other waste. An operator is asking for serious trouble if he doesn't know the characteristics of the waste coming to his plant. Many industries will not be influenced much by a city's plea for improvements unless proof is available. There is no substitute for standard sampling and testing procedures.

SAMPLING TECHNIQUE

1. **Introduction.** Laboratory analyses have little value or meaning if the material analyzed is not fairly representative of the conditions which actually prevail. A big obstacle to the collection of a

representative sample is the lack of homogeneity of sewage, particularly in its raw state as it arrives at the plant. Sewage is an ever-changing mixture of waste materials in solution and in suspension. An ideal location for securing a sample is difficult to find. An acceptable sampling point is a position slightly beneath the surface where turbulence is mixing the sewage thoroughly. There is no ideal time to sample sewage since its quality is varying continuously. A sample may be taken at any moment, but it must be interpreted only on the basis of the conditions at that particular moment.

2. **Types of Samples.** There are two types of samples that may be collected depending on the time available, the tests to be made, facilities available and the objectives of the tests. One is called a "grab" sample and consists of a portion of sewage taken at one particular time. The other is called a "composite" sample and consists of portions of sewage taken at regular time intervals (1 hour, 2 hours, 3 hours, etc.), the volume of each portion of sewage being proportional to the sewage flow at the time the portion is collected. All the portions are mixed to produce a final sample representative of the sewage during that particular collection period.

A. Grab Samples. Grab samples are taken because they are necessary or because there is a lack of time to catch composite samples. For some tests, grab samples must be used. Tests such as residual chlorine, dissolved oxygen, and pH are determined from grab samples as portions of sewage which cannot be mixed. For some tests grab samples can be used because the quality of the component to be sampled remains uniform for a period of a day or longer. An example is a digester sample.

Because in many small sewage treatment plants the time available for sampling is so limited, grab samples are frequently used for biochemical oxygen demand (BOD) tests. This type of sample should be collected when the sewage treatment plant is operating under maximum load. Grab samples are not too reliable in sewage treatment plant control in regard to the biochemical oxygen demand (BOD) test, especially for raw sewage. Sample the raw sewage when it is at maximum sewage strength, then wait for that raw sewage to reach the final before collecting a final sample. A large number of grab samples at different times of the day over several days can be of some value.

B. Composite Sample. Composite samples are representative of the character of the sewage over a period of time. Biochemical oxygen demand, settleable solids and suspended solids tests are usually run on composite samples. The effects of intermittent changes in strength and flow are eliminated. The portion collected should be obtained with sufficient frequency to obtain average results. The period of sampling may be varied, covering 4, 8, 12, or 24 hours, depending on available time and the use to be made of the results. The rate of sewage flow must be measured when each portion is taken and the volume of the portion adjusted to the flow at the particular time of the sample.

Samples may be composited either by mechanical samplers or by hand. If the composite is by hand, the frequency of collection and length of composite should be indicated. Standard Methods states that samples collected for BOD tests must be chilled immediately to 3 to 4 degrees Centigrade and kept at this temperature during the compositing period. BOD values may drop 10 to 40 percent in 24 hours if samples are stored at room temperature.

C. Sampling Principles.

(1) The sample should be taken where the sewage is well mixed.

(2) Large particles which may be in the sewage should be broken into smaller pieces or excluded.

(3) No deposits, growths or floating materials that have accumulated at the sampling point should be included.

(4) Samples should be tested as soon as possible. Samples should be kept cold if test samples are not set up immediately (see previous discussion).

D. Example of the Collection of a Composite Sample. Assume that from past flow records an operator knows that the daily average plant flow is approximately 2.0 million gallons per day (mgd). Further assume that the operator wishes to collect a total sample volume of approximately 2.4 liters in order to have available sufficient sample volume for test requirements. The following represents the influent flow rate into the plant at various times during a 24-hour period:

Time	Flow Rate, MGD
Midnight	1.0
2 A.M.	0.8
4 A.M.	0.6
6 A.M.	0.8
8 A.M.	1.0
10 A.M.	3.0
Noon	3.0
2 P.M.	3.0
4 P.M.	2.4
6 P.M.	2.4
8 P.M.	2.0
10 P.M.	2.0

Table 8-1

The 24-hour flow period has been divided into 12 separate 2-hour periods. Therefore, the total volume of flow represented by each 2-hour period is determined as follows:

$$\text{Volume Per Hour} = \frac{\text{Flow Rate (MGD)}}{\text{24 Hours/Day}}$$

$$\text{Volume for 2 Hours} = 2 \text{ X Volume Per Hour}$$

Therefore, the volume represented between 2 P.M. and 4 P.M. (2 hours) = 2 hours X $\frac{\text{0.1 million gallons}}{\text{hours}}$ = 0.2 million gallons. Similarly, the volume of flow represented by each of the 12 2-hour periods may be determined as follows:

Time	Flow Rate, MGD	Volume Represented, MG
Midnight	1.6	.133
2 A.M.	1.2	.100
4 A.M.	1.0	.083
6 A.M.	0.8	.067
8 A.M.	1.0	.083
10 A.M.	3.0	.250
Noon	3.0	.250
2 P.M.	3.6	.300
4 P.M.	2.4	.200
6 P.M.	2.4	.200
8 P.M.	2.0	.167
10 P.M.	2.0	.167
		2.000

TABLE 8-2

Since a total sample volume of 2.4 liters is desired, it will be necessary to collect $\frac{\text{2.4 liters}}{\text{2.0 MG}}$ = 1.2 liters of sample for each 1.0 MG of flow. Therefore, the required sample amount for each 2-hour period can be determined as follows:

Volume of flow for sample period (MG) X $\frac{\text{1.2 Liters}}{\text{MG}}$ = liters of sample required to be collected. Therefore, at 4 P.M. in our example the operator would collect a sample volume of .200 MG X $\frac{1.2}{\text{MG}}$ = 0.24 liters or since 1 liter = 1,000 milliliters, 0.24 l = 240 ml. Similarly, the sample volume for each of the 12 shown periods may be calculated as follows:

Time	Flow Rate MGD	Volume Represented MG	Sample Volume Required, ML
Midnight	1.6	.133	160
2 A.M.	1.2	.100	120
4 A.M.	1.0	.083	100
6 A.M.	0.8	.067	80
8 A.M.	1.0	.083	100
10 A.M.	3.0	.250	300
Noon	3.0	.250	300
2 P.M.	3.6	.300	360
4 P.M.	2.4	.200	240
6 P.M.	2.4	.200	240
8 P.M.	2.0	.167	200
10 P.M.	2.0	.167	200
			2400 ml = 2.4 liters

Table 8-3

The calculations are similar for any other flow rate and required sample amount.

3. **Sampling Equipment.**

A. Automatic Sampling Equipment. Some equipment is designed to collect composites in proportion to sewage flow by taking a portion at regular time intervals, with sample size varying with flow, or taking uniform portions on a time schedule varying with the total flow. Other equipment is designed to collect uniform portions at regular time intervals.

Automatic sampling offers these advantages: Elimination of errors inherent in manual sampling; reduction of personnel requirements and costs; elimination of a routine task which may become an undesirable chore; and allowance for more frequent collection of portions than is practicable by manual sampling.

The limitations of mechanical samplings include: equipment requires considerable maintenance; close attention is required when sampling raw or partially treated sewage containing large particles; equipment is restricted to size of feed pipe, width of scoop, etc.; usually, individual portions must be small if very large receiving containers are to be avoided; and daily cleaning of all parts in contact with sewage is mandatory.

B. Manual Sampling Equipment.

(1) dipper. A long-handled dipper of stainless steel, plastic, or other corrosion-resistant material is recommended. The dipper should be cylindrical in shape with a wide-mouth opening (minimum of two inches). It should be large enough to contain the largest portion to be collected.

(2) digester samplers. To collect samples of sludge from different depths in a tank, a sampling apparatus made of cast iron or brass weighted with lead can be used. It can be lowered into the tank by a link chain which carries markings show-

ing the various depths. The apparatus is fitted with valves operated by a cord. A pull on the cord at the desired depth opens the valves and the sludge flows in at the bottom while air escapes at the top. A wide-mouthed stoppered bottle attached to the end of a pole can also be used. The bottle is pushed to the desired depth and the stopper removed by means of an attached cord. Many separate sludge digestion tanks are equipped with sampling taps at various depths. Sufficient sludge must be wasted to free the lines of accumulated sludge so that the sample collected will be representative of the sludge in the tank.

(3) drying bed samplers. To collect samples of bed-dried sludge, take portions of equal size from several scattered points on the bed, taking care not to include sand. Mix the samples thoroughly after pulverizing, and use about 500 grams for the laboratory sample.

Samples of filter cake sludge may be collected by cutting portions of the cake as it is discharged from the filter. A cookie cutter is a convenient way to obtain equal sized portions. These portions can then be examined individually or mixed to yield a composite sample.

(4) hand-operated pump. A tube fixed to the suction of an ordinary "pitcher" pump may be lowered to a desired point from which a sample is to be collected.

(5) cross-section sampler. For stratified solutions, such as sludge in digesters or sludge blankets in settling tanks, a glass or plastic tube, open at both ends, may be used. The tube is lowered through the tank cutting a cross-section sample. When in position, the lower end is closed by pulling a rubber stopper into place with a fine line or wire.

4. **Selection of Sampling Points.**

A. Settling Tank Effluent. Samples should be taken at the discharge of the effluent trough or pipe, or in the effluent trough, or in the settling tank just ahead of the discharge weir. These comments apply equally to primary, intermediate, and final sedimentation.

B. Trickling Filter Influent. A wide-mouth jar placed on the media below the distributor arms will usually suffice.

C. Trickling Filter Effluent. A sample may be collected in filter effluent trough, if accessible, or in inlet to secondary settling tank.

D. Aeration Tank Mixture. Samples should be collected in locations having as much turbulence as possible.

E. Chlorine Residual. For single-stage chlorination, collect the sample at the point of discharge of the effluent to the receiving waters.

F. Sand Filter Influent. Collect the sample from the dosing chamber or at the discharge from the distributor onto the sand bed.

G. Sand Filter Effluent. Collect the sample at the discharge of the underdrainage system.

H. Raw Sludge. If raw sludge can be drawn from the settling tank hoppers into a well or pit before pumping, it should be mixed, then a representative sample taken. Also, samples may be collected from openings in pipes near the sludge pumps or from the pump itself.

I. Return Activated Sludge. Samples may be collected from pump suction well, pump or adjacent piping, or at point of discharge of return sludge to the primary effluent. Sample point should be located in the region of good agitation to insure suspension of solids.

J. Supernatant Liquor. Samples may be collected from sampling cocks provided for this purpose in digester control room or through the digester cover opening using a weighted sampler or cross-section sampler.

K. Digested Sludge. Samples should be taken at the point of discharge of the digester draw-off pipe to the drying beds or the drying equipment.

5. **Sampling Methods and Procedures.**

A. Sampling Below Weirs. Care should be taken in sampling below a weir since deposition of solids in the pool upstream from the weir and floating oils or grease just downstream can cause errors in sampling.

B. Sewers and Channels. Care should be taken to avoid skimming the surface (scum and greases), and dragging bottom or sides. A sample collected from the middle third of the cross-section of flow is most desirable.

C. Wide Channels. Samples should be collected from the middle third (vertically) of the channel and the point of collection should be rotated across the channel, always taking care to avoid disturbance of the channel sides and to select a point where the velocity is sufficient to prevent settling.

D. Deep Sewer Manholes. Care must be taken to prevent sludge deposits or side wall scale from entering the sample.

E. Unscreened Sewage. Where it is not practicable to sample raw sewage following screening, a considerable portion of the sewage should be collected in a pail or other large container, then mixed well and sampled as usual.

F. Special Test Sampling Locations. Sometimes samples should be collected from several points in the same tank or channel. For example:

(1) In aerators the maximum dissolved oxygen level is likely to be near the outlet and the minimum near the inlet.

(2) In final settling tank, the maximum dissolved oxygen level probably will be near the inlet and the minimum near the outlet.

G. Sludge. A sample drawn from a sludge pump represents only the quality and concentration of sludge being pumped at the instant the sample is drawn. Since these characteristics may vary rapidly, portions of sludge samples should be drawn into a pail several times during the sludge-pumping operation. The sludge should be well mixed in a container before removing a sample for analysis.

6. **Other Helpful Hints.** The sample volume collected should be large enough for the laboratory test plus an additional amount for a second test in case of doubtful results. Always mix the sample before removing a portion. Remove a portion rapidly after mixing in order not to lose sample homogeneity by settling. Small-tipped pipettes can cause errors by preventing particulate matter from entering the portion of the sample used in the test. These tips can be enlarged by carefully breaking off a small piece. Large-tip pipettes are available commercially.

APPLICATION AND SIGNIFICANCE TESTS TO SEWAGE TREATMENT PLANTS

1. **Flow.** In order to interpret what is happening at each unit of the sewage treatment plant, all process influent and effluent flows should be known. This means sludge flows as well as sewage flows. Also trickling filter recirculation rates and activated sludge return rates should be known. It is imperative that all these flow rates be known at all times of the year and day. A sewage flow can be related to many of the sewage treatment plant tests which are performed. For example, in order to figure the amount of solids going to the digester, the settleable solids and sewage flow must be known or the raw sludge concentration and flow must be known. In order to figure pounds of BOD discharged to a stream the sewage flow must be known. Also, in order to spot infiltration problems, raw sewage flows must be known.

2. **Dissolved Oxygen (D. O.).** Dissolved oxygen is a very significant and frequently used test for indicating the presence of stream pollution. There are two groups of bacteria, aerobic and anaerobic, which are easily stimulated to multiply when a waste is introduced into water. Anaerobic bacteria only multiply when there is a lack of free oxygen (septic condition, obnoxious odor). Different streams have various standards for dissolved oxygen to maintain fish and aquatic life. An operator can observe the effect of his sewage treatment plant effluent on a receiving stream by measuring the dissolved oxygen above and at various points below his plant outfall. The drop in dissolved oxygen is dependent on the strength of the plant effluent, the amount of dilution the stream provides and the condition of the stream. The solubility of atmospheric oxygen in fresh waters ranges from 14.6 milligrams per liter at zero degrees Centigrade to about 7 milligrams per liter at 35 degrees Centigrade at one atmosphere of pressure. The rate at which biological organisms use oxygen to break down waste increases with temperature. Therefore, the most critical stream conditions are during the dry, hot season of the year because there is less oxygen available and the rate of use of the oxygen by bacteria is the highest. Another very critical factor is that there is much less stream flow for dilution of waste effluent in the hot, dry season.

The dissolved oxygen test can be very helpful in sewage treatment plant process control. The most important of these is the activated sludge process. When bacteria are grown in such high concentrations as in the activated sludge process, an outside source of oxygen is needed. The amount of oxygen that is needed is controlled by the dissolved oxygen in the aeration tank and final clarifier. The dissolved oxygen at the effluent weir of the final clarifier should never be zero. If the dissolved oxygen in the aeration tank is measured once a day, a dissolved oxygen of about 3 milligrams per liter is desirable. If the dissolved oxygen in the aeration tank is measured at least every 4 hours, a dissolved oxygen of 1 to 3 milligrams per liter may be maintained. Thus, more flexibility is available with more testing. The operator should be concerned with process efficiency and saving air blower power costs. Over-aeration wastes money.

In the trickling filter plant the more dissolved oxygen in the effluent the better the efficiency. Increasing the recirculation to the trickling filter may increase the dissolved oxygen at the weir of the final clarifier. In any clarifier, the dissolved oxygen, pH and settleable solids tests can help identify problems. For example, if there is too much detention time or sludge withdrawal is too slow the dissolved oxygen would drop noticeably in the clarifier.

In a lagoon with a constant food supply, high concentrations of active algae increase dissolved oxygen levels during daylight hours. A lagoon with a large number of algae usually has the largest dissolved oxygen fluctuation during day and night operation. Many lagoons become supersaturated (more than the amount which can normally be dissolved in water at a specific pressure and temperature) with oxygen. It is very difficult to establish optimum dissolved oxygen levels in aerobic lagoons. If some dissolved oxygen is present, most lagoons operate satisfactorily.

3. **Biochemical Oxygen Demand (BOD).** The biochemical oxygen demand test is widely used to determine the approximate pollutional strength of sewage and industrial wastes in terms of the oxygen that they will require when discharged into natural watercourses. This test is entirely determined by the availability of an organic material (waste) as a biological food and by the amount of oxygen utilized by the microorganisms during biochemical oxidation. Theoretically, an infinite time is required for complete biological oxidation of organic matter, practically however, the reaction may be considered complete in 20 days. However, a 20-day period is too long to wait for results. It has been found by experimentation that a reasonably large percentage (65-80 percent) of the total BOD is exerted in 5 days; consequently, the test has been developed on the basis of a 5-day incubation period.

An incubation temperature of 20 degrees Centigrade was chosen because this is an average stream temperature during the critical warm weather period. The dissolved oxygen test is the main test used in running a BOD test. A dissolved oxygen test is taken on a sample, diluted or undiluted, then incubated for 5 days at 20 degrees Centigrade. Another dissolved oxygen test is taken after 5 days and the difference between the 5-day readings gives the amount of oxygen used by the bacteria in decomposing the waste. This test indicates how well the treatment plant was performing at the time of sampling. BOD is a measure of plant performance, but is not an operating tool. Normal domestic sewage has a BOD in the range of 100-300 milligrams per liter or 0.1-0.2 pounds of BOD per capita per day. Primary treatment or settling alone can be expected to remove 20 to 40 percent of this amount. Secondary treatment accomplishes 85 to 90 percent removal of BOD resulting in a final effluent containing 30 milligrams per liter or less. Advanced treatment can produce an effluent containing 5 milligrams per liter of BOD or sometimes less.

It might be mentioned here that the COD test can be used to measure the amount of organic substance present if toxic substances interfere with bacterial growth in the BOD test. Values obtained from the COD test are considerably higher than those from BOD tests. For normal raw sewage a BOD:COD ratio of 0.5 to 0.7 can be expected.

Because some treatment plants must be large enough to supply the oxygen demanded by industrial wastes, the determination of the amount of BOD from the industrial wastes is often used as a basis for charging the industry for the use of the treatment plant.

The BOD of the treated sewage is the most commonly used means for determining the effect of treated sewage on the receiving stream. This parameter is also used in the design of treatment plants throughout the country.

4. **Relative Stability.** Relative stability may be defined as the percent ratio of oxygen available as dissolved oxygen, nitrite, and nitrate oxygen to the total oxygen required to satisfy the biochemical oxygen demand. The use of this determination is rapidly decreasing since it cannot be related to stream conditions as directly as the BOD. At small plants with limited laboratory facilities, this test is of some value in indicating satisfactory operation. In general a good secondary effluent should have a relative stability of 50 percent or better. If the receiving stream is extremely small the effluent should have a relative stability of 99 percent.

5. **Settleable Solids.** This test is widely used by operators to determine the efficiency of sedimentation units. It is as important in the operation of large treatment plants as in the smaller ones. The term settleable solids is applied to solids in suspension that will settle, under quiescent conditions, because of the influence of gravity. Settleable solids are expressed as milliliters per liter or volume per volume. This test on raw sewage usually ranges from 1-35 milliliters per liter. As a means of control, the settleable solids test can provide a basis for pumping sludge and indicates whether or not sedimentation units are functioning properly.

A. Sludge Pumping Time. In brief, we can express the number of minutes per day of pumping required by the following expression:

$$\frac{\text{Ml/1 Settleable Solids x Flow (TGD)}}{\text{Pump Discharge in GPM}} = \text{Minutes of Pumping per Day}$$

$$\frac{\text{2 Ml/1 x 250 TGD}}{\text{60 GPM}} = \text{8.34 Minutes per Day}$$

The calculation is fairly simple, but consider the factors making up the expression.

(1) Settleable solids in milliliters per liter may vary considerably throughout a 24-hour period. In general, time clocks should be set to cover the night periods when settleable solids concentrations are low. Daytime pumpings should be spaced to remove the excess daytime sludge by changing the time clock setting during the day or by manual pumping periods during the day when the deposition of sludge exceeds the minimum pumping rate set by the time clock. It is important to remove sludge as often as possible in the summer time, but care must be taken to not overpump. Overpumping will add excess water to the digester and will result in a temperature drop in the digester. Also, alkaline materials may be washed out of the tank.

Visual observation of the sludge actually being pumped should be related to this calculation.

(2) pump discharge in GPM.

$$\frac{\text{Stroke in Inches x Area of Piston x No. of Strokes/Minute}}{\text{231 Cu. Inches/Gallon}} = \text{GPM}$$

$$\frac{\text{4 Inches x 78.5 Sq. In. x 44/Min.}}{\text{231 Cu. In./Gallon}} = \text{60 GPM}$$

A 9 in. diameter sludge pump has an area of 63.6 sq. in.

A 10 in. diameter sludge pump has an area of 78.5 sq. in.

A 12 in. diameter sludge pump has an area of 113.1 sq. in.

(3) flow in thousands of gallons per day (TGD). Flow measurements for this basic calculation should be taken at the low flow periods at night for the purpose of setting the time clock. The pumping periods during the day should be checked by using the daytime flow and the average settleable solids measured during the daytime.

(4) number of minutes of pumping per day. The number of minutes of pumping per day should be multiplied by the fraction of the day which it is to cover. For example:

Period	Minutes/Day	Fraction	Setting
Night (min.)	$\frac{\text{2 ml/1 x 200 TGD}}{\text{50 GPM}} = 8$	(8pm-8am) 1/2 day	1 min. every 4 hrs.
Daytime	$\frac{\text{6 ml/1 x 400 TGD}}{50} = 48$	(8am-4pm) 1/3 day	2 min. every hour
Evening	$\frac{\text{5 ml/1 x 300 TGD}}{50} = 30$	(4pm-8pm) 1/6 day	2-1/2 min. every 2 hrs.

Table 8-4

B. Check on the Operation of Clarifiers.

(1) primary clarifier. For normal domestic sewage the primary effluent will not exceed 0.3 milliliters per liter of settleable solids if the clarifier is functioning satisfactorily. When the settleable solids exceed 0.3 ppm look for: poor scum removal, zero dissolved oxygen condition, infrequent sludge pumping periods, short circuiting in the clarifier, and a hydraulically overloaded clarifier.

(2) final or intermediate clarifiers. The settleable solids in final clarifier effluent usually run 0.1 milliliters per liter or less. If the effluent runs high, look for: shortcircuiting and creeping near the weirs, heavily sloughing filter, hydraulically overloaded unit, or warm sewage.

6. **Suspended Solids.** This test measures the dry weight of solids which are retained on an asbestos fiber or millipore filter. The suspended solids are expressed as the dry weight of solids per volume of sewage filtered or milligrams per liter. Suspended solids removal is usually as important as BOD removal for preventing excess stream pollution. In normal domestic sewage the BOD and suspended solids concentrations are nearly the same.

The efficiency of some of the individual treatment units can be determined with this test. For example, primary clarifiers usually average from 50 to 70 percent removal of suspended solids, and secondary treatment usually removes 85 to 90 percent suspended solids.

The suspended solids test is very important in an activated sludge process. The mixed liquor in an aeration tank of an activated sludge plant is sampled for suspended solids (MLSS–Mixed Liquor Suspended Solids) to control the ratio of incoming sewage load (BOD) to the number of organisms (MLSS) held in the aeration tank. This ratio must be determined by experimentation at each plant. In order to maintain a given solids concentration in the aeration tank, the sludge return from the final clarifier must be carefully regulated. The MLSS in a conventional activated sludge process usually ranges from 1,000 to 6,000 milligrams per liter (average is 2,500).

7. **Percent Settleable Solids in Thirty Minutes for Aeration Basins and Sludge Volume Index (SVI).** Sludge volume index is an indication of the density of the MLSS. The lower the number, the faster the sludge will settle. The SVI is the volume in milliliters of one gram of activated sludge in the mixed liquor which has settled for 30 minutes. It is computed by dividing the volume of settleable sludge by the suspended solids milligrams per liter and multiplying by 1,000. The volume of the settleable sludge is equal to the milliliters of sludge which settles from a 1 liter sample in 30 minutes.

$$\frac{\text{Volume of Settleable Sludge, ml}}{\text{Mg/1 Suspended Solids (MLSS)}} \times 1{,}000 = \text{SVI}$$

When holding the volume of sludge constant, the higher the MLSS, the lower the SVI and the faster the settling. When holding the MLSS constant, the smaller the volume of settleable solids in 30 minutes the lower the SVI and the faster the settling. A good operating range for SVI is 60 to 250, but this will have to be determined by experience at any specific plant.

8. **Volatile Suspended Solids.** Volatile suspended solids are those suspended solids which are burned at 600 degrees Centigrade. This parameter provides a rough indication of the amount of food available for the bacteria. They are expressed as percent suspended solids. This is a valuable tool in determining the load to an activated sludge process.

9. **Dissolved Solids.** The results of this test are expressed as mg/l and are obtained by subtracting suspended solids from the total solids. This test is not currently used extensively in sewage treatment but may become more important with the advent of advanced treatment. This test is used much more in the area of water supply. In most instances, the dissolved solids present in the original water represent such a large and variable percentage of the total amount found in polluted water or sewage that it is impossible to evaluate data unless the amount of solids originally present in the carriage water is known.

10. **Total and Volatile Solids.** The total solids test is run by drying a sample of sewage. Dry solids from the total solids test are burned at 600 degrees Centigrade to determine the volatile solids content. Total volatile solids are usually expressed as a percent of the total solids. The total and volatile solids determinations are important in the analysis of raw and digested sewage sludge. Both are subject to some error because of the loss of volatile organic compounds during the drying process. The more the volatile solids are reduced in digestion, the more stable the digested sludge. Good digestion will reduce the volatile solids from 60-75 percent to 30-55 percent.

Also, total volatile solids are important in analyzing the organic food which enters the activated sludge process. Through experience, an operation can relate food supply (total volatile solids) to the concentration of solids (MLSS) in the settling tank.

11. **pH.** At pH values below 6.0 or above 9.0, organisms which stabilize wastes are inhibited. When a plant is treating normal sewage, the pH of the raw sewage should be in the range of 6.8 to 7.6. A wide or prolonged variation from this range should be checked. One of the following is probably the cause of an abnormal pH:

Industries discharging material of high or low pH
Slow flow velocity and hence septic sludge deposits in the sewers
Abnormal pH in the water supply
Septic sewage from any cause

To overcome these problems:
Check the pH of the water in the city supply.
Contact the industries and attempt to work out a program with them to reduce the waste or pretreat it.
Try to get correction on sewer grades and in the meantime, establish a sewer flushing program.

One can watch the performance of a primary clarifier with the pH test. You can expect to get a slight drop in pH across a clarifier, but normally this should not exceed 0.2 to 0.3. If it does for any period of time, the cause should be investigated. The most common causes of excessive pH drops are as follows:

Sludge not pumped often enough or removal not effective;
Too much digester supernatant at one time; or,
Excessive retention period.

These conditions are often a prelude to odors, hence corrective measures should be undertaken promptly. The following may help:

Prechlorination – kills the users of oxygen
Preaeration – adds oxygen
Be sure the sludge collectors move sludge to removal pit and that sludge is removed before it is septic.

These same ideas can be applied to a secondary clarifier to a lesser degree. Remember to use the settleable solids and dissolved oxygen tests to help evaluate clarifier problems.

The pH test is also helpful in digester operation. The organisms which promote rapid digestion, good sludge gas production, and the least amount of odor and nuisances from the digested sludge operate most effectively at a pH of about 7.0. A properly operated, heated digester will maintain a pH of 6.8 to 7.3. If the pH starts to drop below 6.8, you are getting out of the proper methane-producing range and can usually expect trouble. The principal causes of trouble are:

- Operating temperature dropping
  - Excessive amount of water pumped with sludge
  - Gas leak
  - Very cold weather
  - Poor heat exchange
- Industrial waste with high or low pH
- Digester capacity insufficient
- Contents in digester not mixed enough
- Scum and grit taking up too much capacity

A pH above 6.8 cannot be maintained in unheated digesters during the winter, in the Pacific Northwest. These digesters easily get into trouble.

When the pH in a digester goes down below 6.6, trouble usually follows. The solution is to add enough caustic (OH^-) to bring the pH back up to 7.0. This is usually done with lime [$Ca(OH)_2$] or aqueous ammonia [NH_4OH]. When using lime, be sure to make a slurry thoroughly before putting it into the digester. To determine how much caustic is necessary, take a grab sample which is well representative of the entire digester contents. By trial and error, determine how much caustic is needed to neutralize the sample. Then add the caustic in the same proportion to the rest of the digester. After bringing the digester up to pH 7.0, maintain the pH with additional caustic. If there are two or more digesters, direct the raw sludge to a properly operating digester. This helps the sick digester to recover.

Note: The pH test detects a problem long after it has started. This is usually too late. Volatile acids, alkalinity, and CO_2 tests provide more reliable and complete information for digester control. These tests show a problem sooner than pH alone thereby making the problem much easier to solve.

12. **Alkalinity.** The alkalinity test is used to determine the buffer capacity of a digester. This alkalinity is caused by bicarbonates and other salts of weak acids when dealing with a pH of less than 8.3. Alkalinity ranges from 1,500 milligrams per liter to 4,000 milligrams per liter in a normally operating digester. If there is a significant decline in alkalinity over a period of several tests from the normal digester operation, the digester might be heading for trouble, especially if the pH drops significantly at the same time. As alkalinity (expressed as milligrams per liter as $CaCO_3$) decreases and volatile acids (expressed as milligrams per liter as acetic acid) increases and they both approach the same value, a digester is most likely in trouble.

13. **Volatile Acids.** In normal digester operation, the acids produced in the first stage of digestion are used by the methane bacteria in the second stage of digestion. If the methane bacteria do not function as they should, the acids from the first stage will build up, further destroying a favorable environment of the methane bacteria. The volatile acids test is a measure of the acids from the first stage of digestion. Usually the volatile acids of a normally operating digester are 50 to 250 milligrams per liter expressed as acetic acid. When the volatile acids rise above 1,000 mg/l or equal the alkalinity and the pH starts dropping, trouble is likely to be near. Caustic (OH^-) must be added to raise the pH back to 7.0. Refer to the section on pH and alkalinity.

14. **Temperature.** Basically, all biological processes proceed more rapidly at higher temperatures. This is true in all forms of secondary biological treatment such as lagoons, trickling filters and activated sludge. In the anaerobic digestion process, temperatures of 95 to 100 degrees Fahrenheit produce the highest rate of digestion. Temperature records should be maintained on the raw sewage as well as on the sludge in the digesters.

Industrial wastes may increase the temperature of raw sewage. Excessive infiltration can be detected at times by raw sewage temperature records. When the dissolved oxygen test is run, it is desirable to know how near saturation it is at a certain temperature, since dissolved oxygen saturation varies with temperature.

15. **Chlorine Residual and the Most Probable Number of Coliform Bacteria Per 100 Milliliters (MPN).** Chlorine is widely used as a disinfectant for water and sewage treatment processes. It is imperative that chlorine is present in the recommended concentrations if an adequate job of disinfection is to be accomplished since the kill of

bacteria is a function of contact time and concentration. The time of contact is fixed by the size of the treatment units and sewage flow. Too little chlorine is a waste since very little good is accomplished. Whenever the detention time is less than one-half hour, the combined chlorine residual should be 0.75 milligrams per liter or greater. These requirements are based on the orthotolidine colorimetric test. The color should be read about 5 minutes after the orthotolidine is introduced into the sample. If a chlorinator is set on one reading all day, the minimum chlorine residual standard should be met at the highest sewage strength and flow for the day. In other words, at no time of the day should the chlorine residual be below the minimum standards. An even better way of making sure a specific treatment plant is doing a good job of disinfection is to run samples for chlorine residual and MPN at the same time.

MPN is commonly referred to as the most probable number of coliform bacteria per 100 milliliters of sample. One of the most important groups of coliform bacteria are from the intestines of warm-blooded animals. The more coliform bacteria that are present, the higher the probability of pathogenic organisms being present in a sample. Chlorine is used to kill pathogenic organisms, such as those causing typhoid and dysentery. The effectiveness of chlorination for destroying virus is not well known.

16. **Phosphates (PO_4) and Nitrogen (N).** In raw sewage, there is usually from 20 to 30 milligrams per liter of ortho-phosphates and from 35 to 50 milligrams per liter total nitrogen. Detergents contribute over 50 percent of the phosphates in sewage. In the biological treatment of sewage, certain nutrients are needed and sometimes have to be added when a treatment plant has a high industrial waste load. One part phosphates for every 90 to 150 parts BOD and one part nitrogen for 17 to 32 parts BOD are needed to balance the nutrient needs of the biological organisms.

At present, phosphate removal is in the development stage. The most promising processes to date are the modified activated sludge plant and lime coagulation or a combination of the two processes. These processes can obtain 70 to 95 percent phosphate removal. Phosphate and nitrogen removal is important because these two compounds are major nutrients which stimulate the growth of algae. Phosphates are the most important because nitrogen can be fixed from the atmosphere. Borderline concentrations which tend to start or retard algae growths are 0.01 to 0.1 milligrams PO_4 per liter and 0.2 to 15.0 milligrams N per liter.

In most treatment plant effluents, orthophosphate (soluble) is the most important to measure. This form of phosphate is immediately suitable for algae metabolism. Phosphates can be tied up in algae tissue as organic phosphates.

LABORATORY TESTING

1. **Introduction.** Sewage treatment plant operation should be geared so laboratory tests are made to aid efficient operation of the plant. Tests should also be made to obtain data that can be used in future design. It should always be a policy to run enough tests to determine what happens upstream from the plant effluent outfall, what happens in the plant, and how the plant operation affects downstream water quality.

This section is designed to emphasize laboratory work in terms of equipment, cleanliness and techniques. All tests are from **Standard Methods for the Examination of Water and Wastewater,** Twelfth Edition, 1965, as published by American Water Works Association, American Public Health Association and Water Pollution Control Federation. Tests and information included are for clarification and do not duplicate the Standard Methods presentation.

2. **Care and Cleaning of Laboratory Equipment.** Laboratory equipment and the laboratory itself should always be kept clean and in good working order. A few rules are necessary to insure proper data from treatment plant laboratories.

A. Care of Laboratory Equipment. Before using any piece of equipment make sure:

(1) that you understand the use and intention of the instrument (instruction manuals are nearly always available–read the manual before touching the instrument)

(2) that the contemplated operation can be done safely and that it will not interfere unnecessarily with anyone else

(3) that the instrument is properly calibrated and adjusted and that it is not moved from a fixed location without recalibration and adjustment.

If something doesn't work easily, **Don't Force It!** The old adage, "Don't force it; get a bigger hammer," doesn't work on laboratory equipment. Parts are delicate and can easily be damaged.

Broken glassware is extremely dangerous. Every effort should be made to keep bottles, flasks and other glassware in cupboards so they cannot be accidently broken. Don't leave glassware and other breakable equipment in precarious locations. The

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guilty person is the one who placed it there—not the one who knocked it down! Lay graduated cylinders down, with the mouth over the center gutter, if further use is necessary. Otherwise, clean and return to the cupboards.

B. Care in Use of Chemicals.

(1) poisons and irritants. (If serious, first call a physician.) All poisonous chemicals are so indicated on the container in which packaged, along with the recommended external and internal antidotes. In general, acids and alkalies can be handled as follows:

Acids:	External –	Flush with water and follow with sodium bicarbonate solution.
	Internal –	Administer milk of magnesia (magnesium hydroxide).
Alkalies:	External –	Flush with water and follow with dilute acetic acid solution provided for the purpose; if in the eyes, use boric acid.
	Internal –	Administer large quantities of water with vinegar or citrus juices.

(2) reagent bottles and chemicals. Return all reagent bottles and chemicals to their designated locations after removing the amount needed. Do not allow reagent bottles to drip on shelves.

C. Cleaning of Laboratory Equipment.

(1) tables and shelves.

Care:

Avoid spilling chemicals of any kind on tables; when practicable, place burettes and other equipment over an enameled tray or other protective material; handle strong acids and caustic solutions over sink.

Cleaning:

Should a **strong acid solution** be spilled, soak up with a dry rag, rinse rag thoroughly, and then wash table with a solution of sodium bicarbonate.

Should a **strong alkaline solution** be spilled, soak up with a dry rag, rinse rag thoroughly, and then wash table with a weak solution of boric or acetic acid.

Should a **solvent** be spilled, wipe up as much as possible with a dry rag and then scrub with a wet rag.

At the end of each period, wash down all tables with disinfectant.

(2) clothing.

Care:

Avoid wearing woolen clothing in the lab; acids and some other chemicals readily attack animal fibers. Wear a lab apron at all times and keep shirt sleeves rolled up. Shoes should be heavily coated with polish.

Cleaning:

If **acid-spotted,** neutralize immediately with sodium bicarbonate.

If **alkali-spotted,** neutralize immediately with weak solution of boric acid; apply liberally.

(3) glassware (general).

Care:

Avoid permitting staining solutions and solutions containing suspended materials to stand longer than necessary; the easiest time to wash is immediately after use.

Cleaning:

Resistant materials are generally removed by a small amount of acid-dichromate cleaning solution. **Do not dip brushes in this acid solution!** Follow up with thorough washing with soap and water. Rinse in tap water. Allow to air dry.

(4) glassware (burettes).

Care:

Be careful not to use more stop-cock lubricant than is necessary; too much will plug the burette.

Cleaning:

Should the tip of the burette become plugged with grease, it can usually be removed by filling the burette with hot water and holding the tip beneath the hot water tap. It may be necessary to pierce the grease with a fine wire. The rest of the burette may be cleaned as ordinary glassware. If a dry burette is necessary, rinse with a small amount of alcohol and dry with compressed air.

(5) glassware (pipettes).

Care:

Before using any pipette in a solution containing suspended matter, decide first whether such use is necessary or whether some other more easily cleaned device can be used without interfering with results. If it must be used in such a solution, rinse out immediately after use, and clean as below.

Cleaning:

All pipettes should be filled with acid-dichromate cleaning solution, allowed to soak if necessary, rinsed thoroughly and placed in the appropriate place in the cupboards.

The accuracy of any chemical analysis may be greatly influenced by the cleanliness of the equipment used. The walls of volumetric glassware must be free of foreign matter since the presence of extraneous matter may cause incomplete drainage and hamper the correct formation of the meniscus. There are many glass cleaning solutions available. The choice of the solution will depend upon the nature of the adhering matter. A solution of warm water and either detergent or trisodium phosphate is widely used. Dichromate-sulfuric acid cleaning solution is used when a strong oxidizing acid cleaner is needed. Alkaline cleaning solutions are used to a less extent. The recipe for most of the compounded glass cleaning solutions can be found in the chemistry handbooks.

**Don't let this happen to you!
Clean all equipment after use!**

Figure 8-1

A. Balance, Analytical, Weights.

This is an extremely accurate set of weights for use with the analytical balance.

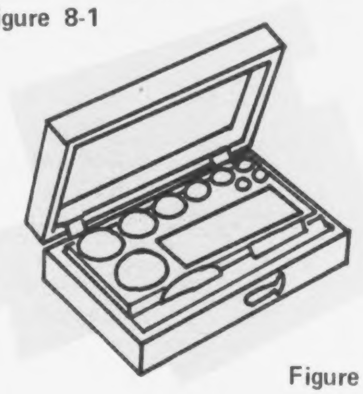


Figure 8-2

B. Balance, Double Beam.

This balance is used for rapid and relatively accurate weighting to within 0.1 gram. The instrument is used to weight chemicals and samples where a high degree of accuracy is not desired.

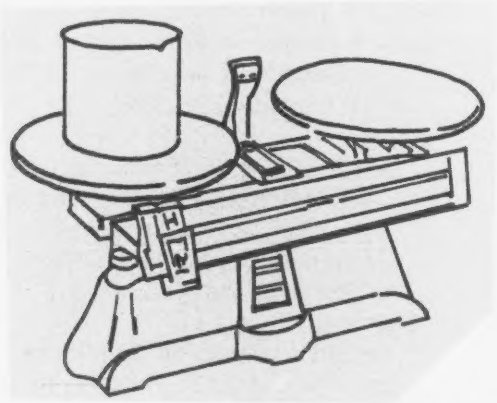


Figure 8-3

C. Beakers.

This container may be made from one of a variety of types of glass, plastic, or stainless steel. The most widely used beaker is the "Griffin" type made from "Pyrex" brand glass. This vessel may be used in boiling solutions, preparing reagents, volumetric titrations, or flocculation tests. There are also a variety of nontechnical uses.

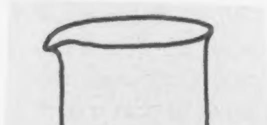


Figure 8-4

D. Bottle, BOD.

This is a bottle especially designed for use in the determination of dissolved oxygen and the Biochemical Oxygen Demand (BOD).

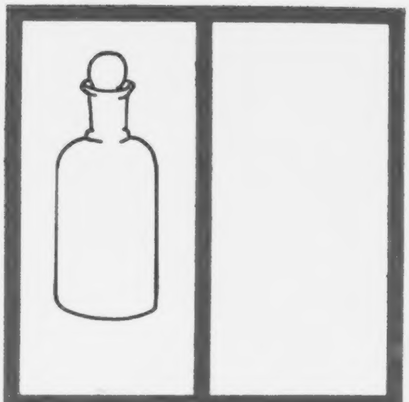


Figure 8-5

E. Bottle, Carboy.

This is a large narrow-neck bottle made either of soft glass or "Pyrex." They are available in sizes ranging from 2- 1/2 to 12 gallons. This bottle is used for the storage of large quantities of liquids, notable dilution water for the BOD determination.

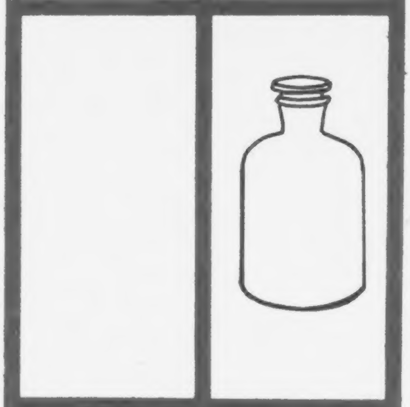


Figure 8-6

F. Bottle, Dropping.

This is a small bottle designed to deliver its contents dropwise. It is used for dispensing indicators used in volumetric titrations.

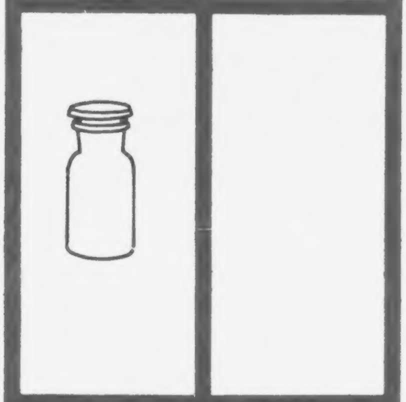


Figure 8-7

G. Bottle, Reagent Type.

This container may be made of one of a variety of types of glass or plastic. The type of material the bottle is made from will in a large part dictate its use. Alkaline solutions should be stored in either "Pyrex" glass or plastic bottles. Other solutions may be stored in the less expensive soft glass bottle. Solutions which are light sensitive such as silver nitrate, should be stored in smoked glass (low actinic glass) bottles. This container is used for the storage of chemical solutions.

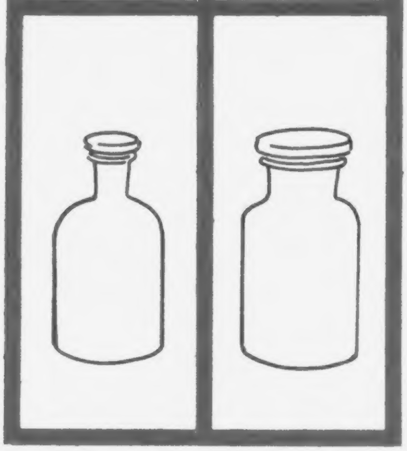


Figure 8-8

H. Burette.

This is an accurately calibrated instrument used to dispense liquids. By manipulation of the stopcock the rate of flow may be controlled to a high degree. The instrument is used in volumetric titrations.

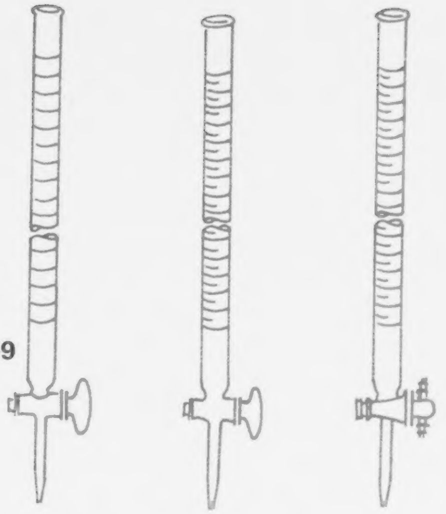


Figure 8-9

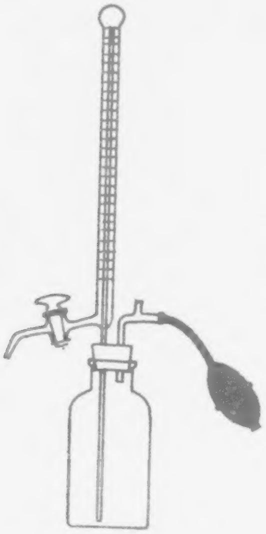


Figure 8-10

I. Correct Method of Reading Calibrated Volumetric Equipment.

When a liquid is placed in a container, a curved surface between the air and liquid (meniscus) is formed. In the case of colorless or colored solutions which are transparent, the lowest point on the meniscus is chosen as the reference point. If the solution is intensely colored, extreme difficulty may be encountered in observing the bottom of the meniscus, thus the top of the meniscus is used as the reference point.

No matter which of the above mentioned points on the meniscus is used, care must be taken to sight the reference point on the same level as the plane of the graduation mark. The effect of the eye position in sighting the meniscus is illustrated. If the eye level is above the reference point on the meniscus as in Position 1, the observed reading will be lower than the actual value. Eye level position on the same plane as the calibration as in Position 2, will give an accurate reading. If the eye level is below the reference point as in Position 3, a value higher than the actual value will be obtained.

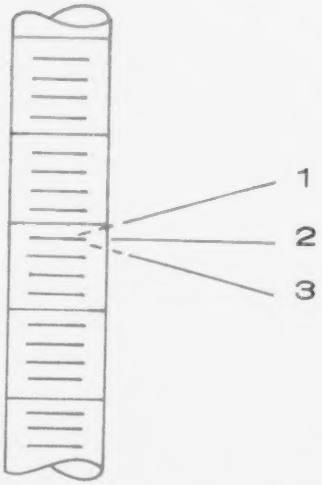


Figure 8-11

J. Burner, Bunsen.

A gas burner used in laboratory work for heating solutions.

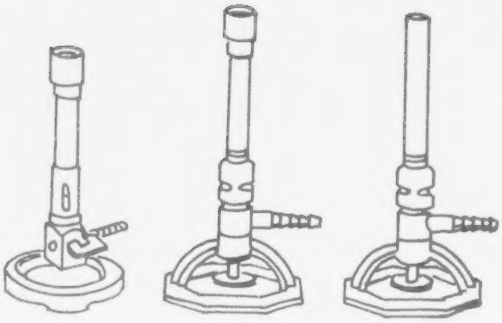


Figure 8-12

K. Clamp, Burette Double Holder.

This clamp is designed to hold one or two burettes in a vertical, rigid position. The self-locking device which holds the burettes in position can be easily manipulated in raising or lowering the burette.

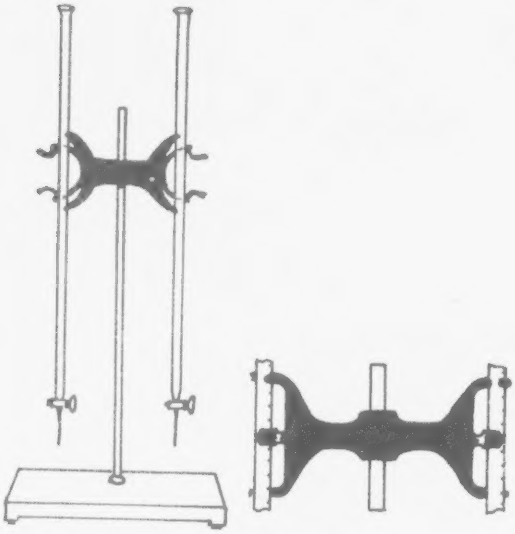


Figure 8-13

L. Clamp, Hosecock.

This is a heavy duty device used in regulating the flow in rubber tubing.

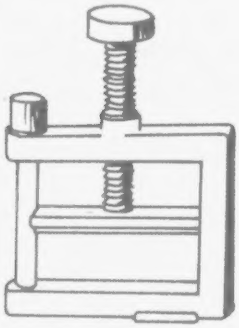


Figure 8-14

M. Clamp, Pinch.

This device allows the stoppage of flow through thin-walled rubber tubing.

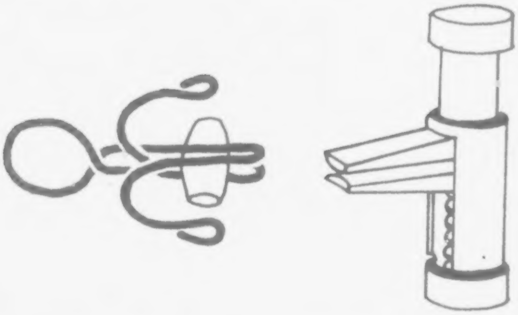


Figure 8-15

N. Clamp, Utility.

This device is used to hold a piece of apparatus rigidly in place. The versatility of this instrument lies in the fact that the jaws of the clamp can be adjusted to fit tightly to the piece of apparatus.

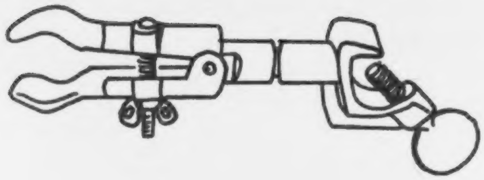


Figure 8-16

O. Cone, Imhoff.

This is a cone graduated to contain one liter. The lower portion (tip) of the cone is graduated to read in milliliters. The apparatus is used in the settleable solids determination.

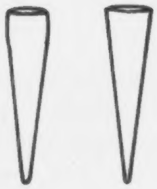


Figure 8-17

P. Crucible, Gooch, Porcelain Glazed.

This is a glazed porcelain cup having a perforated bottom. It is used in the suspended solids determination.

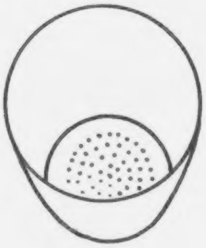


Figure 8-18

Q. Cylinder, Graduated.

This glass cylinder is graduated such that a relatively accurate volume may be measured.

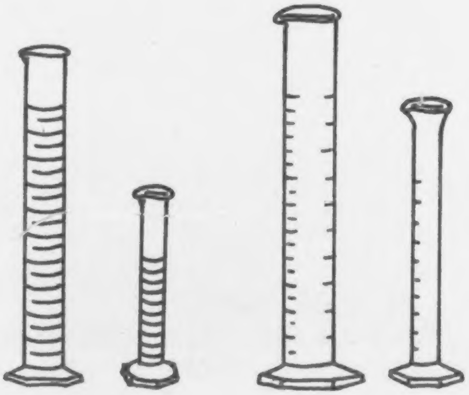


Figure 8-19

R. Desiccator.

This is a two level container with a removable dome shaped lid. In the bottom level a desiccant, usually anhydrous calcium chloride, is placed. The levels are separated by a glazed perforated porcelain plate upon which materials in containers are allowed to come to room temperature free of moisture.

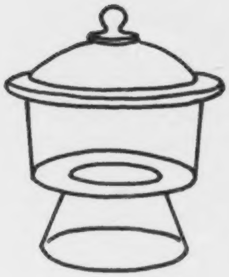


Figure 8-20

S. Dishes, Evaporating.

This vessel is designed to hold a sample, while the sample is evaporating, drying or igniting. Used in the solids determination.

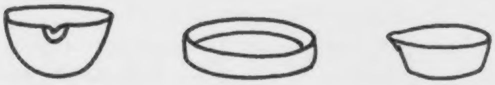


Figure 8-21

T. Flask, Erlenmeyer.

A special type of flask used in volumetric determinations, heating or mixing samples with water.

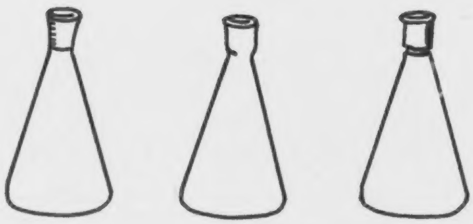


Figure 8-22

U. Flask, Florence.

This is a flat bottom flask used for boiling liquids.

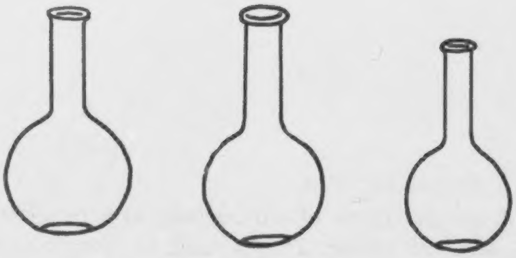


Figure 8-23

V. Flask, Suction.

This is a heavy-walled flask similar in appearance to an Erlenmeyer flask; in addition it has a side arm where suction may be applied. The flask is used for vacuum filtration as in the suspended solids determination.

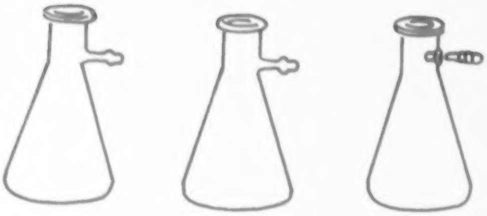


Figure 8-24

W. Flask, Volumetric.

This is a thin-walled flask which is very accurately calibrated to contain a known volume. The flask is used in the preparation of standard solutions and reagents.

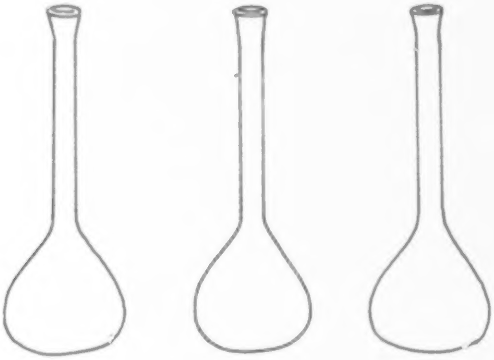


Figure 8-25

X. Furnace, Muffle.

This is a well insulated, high temperature, electric furnace. It is used in the determination of fixed and volatile solids.

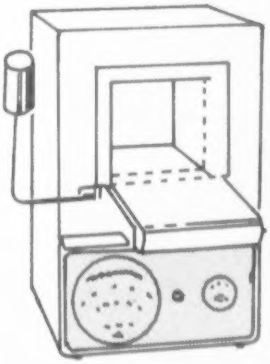


Figure 8-26

Y. Gauze, Wire.

A special piece of wire screen with or without an asbestos center. This is used to distribute the heat from a flame more evenly.

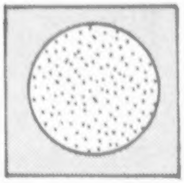


Figure 8-27

Z. Oven, Drying.

An electrically heated oven used to remove last traces of moisture from a sample. The temperature can be set by a calibrated dial on the thermostat.

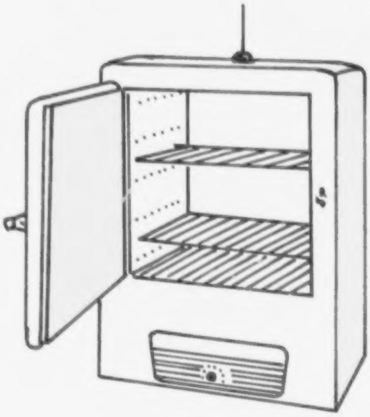


Figure 8-29

AA. Pipette, Mohr.

This is a relatively accurately calibrated dispensing tube with subdivisions in the range of 0.1 to 1 ml. Those most commonly used have total capacities from 1 to 10 milliliters.

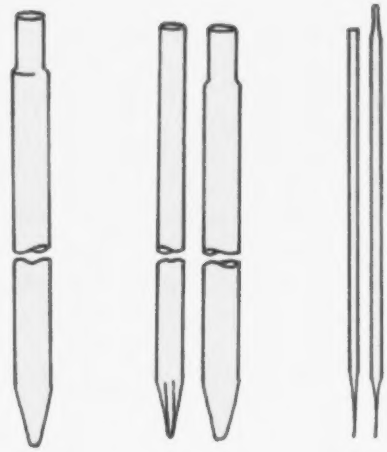


Figure 8-30

BB. Pipette, Volumetric.

This is a highly accurate dispensing tube calibrated to deliver a specific volume. The commonly used capacities are from 5 to 200 ml.

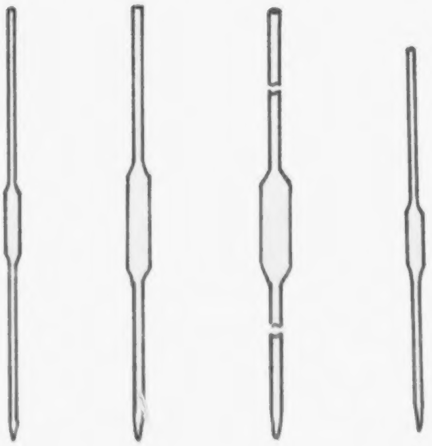


Figure 8-31

CC. Support, Rectangular Base.

This apparatus is used to support other equipment.

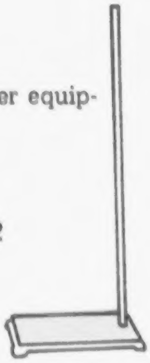


Figure 8-32

DD. Tongs.

This is a scissor shaped instrument, made of a corrosion resistant metal, designed to hold objects. Used mainly to remove red hot crucibles or evaporating dishes from the muffle furnace.

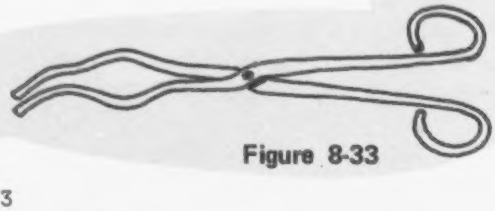


Figure 8-33

TESTING PROCEDURES

CHLORINE RESIDUAL (FLASH)

1. **Definition.** The chlorine residual is that concentration of chlorine residual reacting with orthotolidine reagent. It approximates the "total available chlorine," needed for good disinfection.

2. **Significance.** Disinfection with chlorine is one of the most important parts of sewage treatment. In order to kill bacteria with chlorine, it is necessary to:

A. Add sufficient amount of chlorine, and

B. Provide sufficient contact time for the chlorine applied to be effective.

Most sewage treatment plants are designed to provide 20 minutes of contact, either in a tank or in the outfall line. With 20 minutes of contact time, a residual of 0.5 ppm is usually sufficient to assure good disinfection (MPN of effluent in the range 1000–2400/100 ml). If less contact time is available, then it will probably be necessary to maintain higher residuals to achieve good disinfection.

The amount of chlorine required to produce the necessary residual varies with the composition and strength of any particular sewage.

The application of 5-10 ppm of chlorine (40-80 lb./MG) is **usually** sufficient to produce a flash residual of 0.5 ppm and low bacterial counts in the effluent. The goal, however, is good disinfection, as measured by bacteriological examinations of effluent. If MPN's are repeatedly above 2400, more chlorine is needed.

3. **Procedure.**

A. Color Disk Method.

(1) Fill both tubes to mark with sample that has had 20 minutes' contact time with chlorine.

(2) Add orthotolidine to mark on dropper to inside tube. Shake well. Do not cover tube with finger.

(3) Rotate disk and watch colors. Read after 5 minutes and record as total chlorine.

B. Comparator Block Method.

(1) Place 10 ml of sewage in 3 test tubes and place the tubes in the comparator block in one row.

(2) Place a tube filled with distilled water in the remaining middle hole.

(3) Add 0.5 ml of standard orthotolidine solution after sewage has had a 20-minute contact time with the chlorine to the middle sample tube. Shake well.

After 5 minutes hold the block up to the light and arrange the color standards so that the color in the center falls between the colors of the outside color standards. Interpolate and record as total chlorine.

pH (SEWAGE)

1. **Definition.** pH is a measure of acidity of the sample, pH = 7 is neutral, pH less than 7 is acid, more than 7 is basic. (pH: The negative logarithm of the hydrogen ion-concentration.)

2. **Significance.**

A. Organisms relied upon in sewage treatment seem to function best when the pH is at or near neutrality (=7).

B. Acid conditions (pH less than 7) leads one to suspect anaerobic decomposition.

C. pH measurement assists in controlling digestion.

3. **Procedure.**

A. Color Disk Method.

(1) Fill both tubes to mark with sample.

(2) Add indicator to mark on dropper to inside tube. Shake well. Do not cover tube with finger.

(3) Rotate disk and watch colors. Read within 30 seconds and record.

B. Comparator Block Method.

(1) Place 10 ml of sewage in 3 test tubes and place the tubes in the comparator block in one row.

(2) Place a tube filled with distilled water in the remaining middle hole.

(3) Add indicator to mark on dropper to the middle sample tube. Shake well.

(4) Within 30 seconds hold the block up to the light and arrange the color standards so that the color in the center falls between the colors of the outside color standards. Interpolate and record.

RELATIVE STABILITY

1. **Definition.** Relative stability is a term used to describe the relative degree of treatment (stabilization) which the decomposable organic matter in sewage has undergone.

2. **Significance.** Well treated sewage leaves little food for bacteria to live on. Consequently, growth of these organisms is slow and, therefore, little oxygen is used up. By determining how long it takes for all the oxygen in a sample of sewage to become exhausted, it is possible to determine how well treated the sewage is.

3. **Description of Test.** Methylene blue (a dye) is placed in a sample of plant effluent and the sample stored where the temperature will be nearly constant at around 68° F. The dye will become colorless when all the oxygen is exhausted in

the sample. The number of days required to decolorize a sample is noted. The longer it takes to use up all the oxygen in the bottle, the more stable the sample is considered to be. A table is provided to convert the number of days to per cent relative stability.

4. **Procedure.**

A. Fill a 300 ml BOD bottle with sample, avoiding aeration.

B. Add exactly 0.8 ml methylene blue solution below the surface of the liquid and mix by inverting the bottle.

C. Incubate in a dark enclosure at 20°C with a water seal. Observe the sample daily until decolorization takes place.

D. Record relative stability percentages figured from table.

Decolorization Time (20°C) Days	Relative Stability Per Cent	Decolorization Time (20°C) Days	Relative Stability Per Cent
0.5	11	8.0	84
1.0	21	9.0	87
1.5	30	10.0	90
2.0	37	11.0	92
2.5	44	12.0	94
3.0	50	13.0	95
4.0	60	14.0	96
5.0	68	16.0	97
6.0	75	18.0	98
7.0	80	20.0	99

Table 8-5

5. **Sample Computations.**

A. Record days required to decolorize sample in laboratory notebook, read percent efficiency off table and record.

Example:

Final Effluent–Test set up	May 1, 1967
Final Effluent–Sample decolorized	May 15, 1967
Final Effluent–Time to decolorize	14 days
Percent Relative Stability	96%

B. Lack of oxygen in final effluent indicates in most cases that sewage has been given poor, incomplete treatment.

C. Gradual decrease of oxygen concentration in primary settling tank effluent may indicate building up of sludge deposits in this tank.

D. Lack of oxygen in effluent from primary settling tank may be one cause of poor secondary treatment.

DISSOLVED OXYGEN (D.O.)

1. **Definition.** Oxygen will dissolve in water in the same manner that salt or sugar will, or that carbon dioxide will in pop or beer. The test for dissolved oxygen is a test to determine how much oxygen there is in a sample of water or sewage at the time of the test.

2. **Significance.** The test for dissolved oxygen (D.O.) is an important part of the BOD test. The test for dissolved oxygen is also used to provide other information concerning sewage, and the treatment plant. Facts which may be established by the D.O. test include:

A. The presence of D.O. in raw sewage indicates that this sewage is relatively fresh.

3. **Description of Test.** The sample to be tested is collected in 300 ml glass-stoppered bottles, care being taken to prevent air bubbles getting in with the sample. Several chemical reagents are added. The chemicals cause the oxygen in the water to be replaced by iodine. The final chemical, sodium thiosulfate, is used to get rid of the iodine color. The amount of thiosulfate used determines the D.O. in the sample.

4. **Procedure.**

Dissolved Oxygen*–Sewage (the sodium Azide Modification of the Winkler Method).

The reagents are to be added in the quantities, order and method as follows, for both 250 and 300 ml bottles: (Numbers in parentheses refer to instructions for preparation of reagents.)

A. Add 2 ml* of manganous sulfate solution. (4)

B. Add 2 ml* of alkaline-iodide-sodium azide solution (5) well below the surface of the liquid.

C. Shake well by inverting the bottle several times; allow the floc to settle to the bottom part of the bottle. This may take about two minutes. Then shake again and allow the floc to settle in the bottom half of the bottle.

D. Acidify with 2 ml* of concentrated sulfuric acid (this is stock concentrated sulfuric acid with a normality of 36 and specific gravity of approximately 1.84) by allowing the acid to run down the neck of the bottle.

E. Shake well and after about 30 seconds, if the brown precipitate has dissolved, the solution will be ready to titrate.

F. Measure 204 ml of sample into an Erlenmeyer flask.

G. Titrate with .025 N. sodium thiosulfate solution (6) until the amount of iodine remaining in the solution is a pale straw color.

H. Add 1 or 2 ml of freshly prepared starch solution (7) and titrate rapidly to the first disappearance of the blue color.

I. The amount of oxygen dissolved in the original solution will be exactly equal to the number of ml of sodium thiosulfate used in the titration.

* Although 2 ml quantities of the reagents insure better contact with less agitation, it is permissible to use 1 ml quantities with 250 ml bottles.

Note: The above mentioned reagents should be kept in fresh supply as they will deteriorate with age and give inaccurate results. This, of course, is also true for BOD determinations. There are now available pre-measured, packaged reagents that will not deteriorate and can be used effectively in cases where dissolved oxygen determinations are not frequently made. The packaged reagents come in various sizes. It is recommended that the 2 ml size be used in order to obtain a comparable degree of accuracy and eliminate investing in additional equipment. With the 2 ml size the equipment and procedure as described above can be followed exactly. The operator is cautioned to closely examine the cost differential as these packaged reagents are definitely more expensive than the self-prepared reagents. At the present, information on these reagents can be obtained by writing to: Hach Chemical Company, P.O. Box 907, Ames, Iowa.

BIOCHEMICAL OXYGEN DEMAND (BOD)

1. **Definition.** During the time organic matter in sewage is being changed by bacteria from the decomposable to the inert stage, oxygen is being used up. The amount of oxygen used up in this action is called the BOD of the sample.

2. **Significance.** The BOD test determines the amount of oxygen required to stabilize the organic material in a sample. Because of the relationship between the organic food, bacteria, and oxygen, this test indicates whether a sewage is strong or weak, and also provides a means of measuring how effective the biological treatment processes (trickling filter and activated sludge) are. Tests on final effluent provide some indication as to how this effluent will affect the stream. The BOD test is similar in nature to the relative stability test.

3. **Description of Test.** The BOD test provides much more information than the relative stability test. The test is much more sensitive, however, requiring more work, more equipment, and careful laboratory technique for accurate results. For this reason, in small plants the relative stability test is often substituted for the BOD test.

The BOD test is made by determining the quantity of oxygen in a sample as it is collected and determining the quantity of oxygen in a duplicate sample after five days incubation at 68°F. (20°C.). The amount of oxygen used up during the five-day period is the difference in the results of the first and last test. The BOD of the sample is based on the amount of oxygen used up in the five-day period, and also on the amount of water used to dilute the sewage in making up the sample.

Column 1	Column 2	Column 3
% Sample Dilution	ml of sample needed/liter	Anticipated BOD Range, ppm.
100	1000	2 – 5
50	500	4 – 10
25	250	8 – 20
20	200	10 – 25
12.5	125	16 – 40
10	100	20 – 50
5	50	40 – 100
4	40	50 – 125
2.5	25	80 – 200
2	20	100 – 250
1.5	15	133 – 333
1	10	200 – 500
.5	5	400 – 1000
.25	2.5	800 – 2000

Table 8-6

4. **Procedure.**

A. To obtain the % sample dilution shown in column 1, add the number of ml shown in column 2 to a liter graduate and fill with dilution water to the liter mark. Stir thoroughly with plunger type rod, being careful not to entrain any air in the sample.

B. Siphon sample from graduate to three BOD bottles and incubate two of these for 5 days at 20° C. (Be sure to keep a water seal around neck of the BOD bottle.)

C. Run an initial DO on the remaining bottle and record as "initial reading."

D. Repeat steps 1, 2 and 3 above for the same station except using a second dilution to provide better accuracy.

E. After incubation for five days (+ 2 hrs.) run a DO on the samples and record as "final reading."

F. The difference in the initial reading of the average in the final reading for each dilution should be between 2 ppm and 5 ppm for maximum accuracy.

G. Column 3 shows the range of BOD's that can be tested using the corresponding % sample dilution in column 1. For example, if you anticipate a BOD in the range of 100-250 ppm (column 3) you would use a 2% dilution (column 1). If you anticipate a range of 100-500 ppm (column 3), you would select 2 and 1% (column 1). The 2 and 1% are selected to allow an overlapping of ranges as follows: 2% – 100 to 250 ppm and 1% – 200 to 500 ppm. You will note that the upper BOD limit for 2% dilution is 250 ppm and the lower limit for 1% dilution is 200 ppm. As can be seen, this allows an overlapping of 50 ppm.

5. **Calculation.**

A. Initial reading (I.R.) minus final reading (F.R.) times one hundred divided by the % sample dilution equals the 5-day BOD in ppm.

B. $(\text{I.R.} - \text{F.R.}) \text{ X } \frac{100}{\%}$ dilution = 5-day BOD in ppm.

C. It must be pointed out that this formula **does not** take into account the BOD of the dilution water (sometimes referred to as the blank) which may vary from 0.1 to 0.5 ppm. This error only becomes significant when BOD's are in the very low ranges. Blanks should always be run with the samples.

6. **Eliminate Errors.**

Check These Items:

A. Was the sample composited proportional to flow?

B. Was the sample iced or held below a temp. of 4°C.?

C. Was the sample free of bactericidal substances?

D. Was the dilution water stored in a room away from direct sunlight?

E. Was the D.O. of the dilution water over 8.0?

F. Did the D.O. of the dilution water drop over 0.2 ppm during incubation? (Should be checked periodically.)

G. Was the sewage added to the bottles accurately?

H. Was the dilution water added so as not to aerate the contents of the bottle?

I. Was the cork placed in the bottle so as not to trap air beneath the stopper?

J. Was a water seal maintained over the bottle stopper during incubation?

K. Was the temperature variation of the incubator not over + 1°C.?

L. Was the standard sodium thiosulfate solution fresh or recently prepared?

M. Were all bottles, reagents, and apparatus clean?

N. Before the test was the dilution water held at a constant temperature at about 68°F. for 24 hours?

O. If sample was chlorinated, was chlorine neutralized?

SETTLEABLE SOLIDS

1. **Definition.** Those solids which will settle out when a sample of sewage is allowed to stand quietly for a one-hour period are called settleable solids.

2. **Significance.** The test for settleable solids indicates the volume of solids which will settle out in a sedimentation tank, assuming perfect settling conditions in the tank. The removal of settleable solids in a sedimentation tank is determined by making tests on the sewage going into the tank and the sewage leaving it.

3. **Description of Test.** The test for settleable solids is run in cone-shaped glass containers called Imhoff cones. Sewage is poured into these cones and allowed to settle quietly for a one-hour period. The amount of solids settling to the bottom is measured.

4. **Procedure.**

A. Fill an Imhoff Cone to the liter mark with a thoroughly mixed sample.

B. Allow sedimentation for 45 minutes.

C. Gently spin the cone to facilitate settling of material adhering to the side of the cone.

D. 15 minutes later, record the number of ml settleable solids subtracting.

5. **Sample Computations.**

A. Record results in laboratory notebook.

Example

Raw sewage (1 hour settling) reads 5 ml.

Primary effluent (1 hour settling) reads 0.2 ml.

B. Compute removal of settleable solids in primary settling tank and record.

$$\frac{\text{Influent} - \text{Effluent}}{\text{influent}} \times 100 = \%$$ removal of settleable solids

$$\frac{5.0 - 0.2}{5.0} \times 100 = \frac{4.8 \times 100}{5.0} = 96\%$$ removal of settleable solids in primary settling

C. Similar records and computations should be made for the final tank effluent and influent.

SUSPENDED SOLIDS

1. **Definition.** All solids (settleable and non-settleable) which are physically suspended in a sample of sewage are considered to be suspended solids.

2. **Significance.** The removal of suspended solids is the prime function of the settling tanks. The test for suspended solids provides information concerning the amount of solids (by weight) removed by the settling tanks.

3. **Filter Paper Method.**

A. Dry three filter papers (9 cm Whatman 4 or No. 7) in the oven at 103° for one hour.

B. Stabilize moisture content of papers by exposing dried papers to room conditions for one hour.

C. Weigh papers to 0.1 mg.

D. Measure 250 ml of sample and filter through paper in 4" Buchner funnel. Moisten one paper with filtrate for use as a blank and apply suction same as sample.

E. Dry papers for one hour and stabilize for one hour the same as before use.

F. Reweigh the papers. Gain in weight corrected by net change in blank is the suspended matter.

PPM S.S. = Weight in Milligrams x 4

Burn the paper and weigh the ash if a separation to ash and volatile matter is desired.

4. **Gooch Crucible Method.**

A. Place a Gooch crucible in a suction flask and pour into it about 25 ml of asbestos emulsion (8) or use glass fiber filters (2.4 cm).

B. Apply the suction gently until the mat is formed with asbestos emulsion or wet fiber mat with distilled water and apply suction.

C. Wash with distilled water until no fibers of asbestos pass through the filter.

*D. Dry the crucible in the 103° C. oven and ignite in a muffle furnace at 600° C. or over a burner, to a cherry red heat.

*E. Allow the dish to cool and moisten the mat with distilled water. Omit if glass fiber mat is used.

F. Dry in the 103° C. oven for 1 hour, cool in the desiccator and weigh to 0.1 mg. Omit if glass fiber mat is used.

G. Measure 25-100 ml of the well-mixed sewage by means of a graduate. Keep the solids in suspension while measuring.

H. Filter the sample through the prepared Gooch crucible and follow with several distilled water rinsings of the graduate. Be sure that all suspended matter is transferred to the crucible.

I. Dry in the 103° C. oven for 1 hour, cool in the desiccator and weigh to 0.1 mg.

*Omit steps D and E if volatile suspended solids are not required.

SAMPLE CALCULATIONS AND RECORDING

Example

Wt. of crucible and solids	15.5999 gm.
Wt. of crucible	15.5817 gm.
Wt. of solids	0.0182 gm.

$$\frac{\text{Increase in weight (gm.)} \times 1{,}000{,}000}{\text{ml. of sample}} =$$ ppm suspended solids

$$\frac{.0182 \times 1{,}000{,}000}{100} = 182 \text{ ppm}$$

Table 8-7

5. **Pyrex Filtering Crucible Method.**

Use medium crucibles or fine crucibles.

A. Heat filtering crucible in 103° C. oven for a short time to drive out the moisture. Then place the crucible in a desiccator and allow it to cool and dry before weighing to 0.1 mg.

B. Follow steps (G), (H), and (I) of part 4.

TESTS ON ACTIVATED SLUDGE

The very nature of the activated sludge method of waste water treatment makes it unique in that large masses of sludge grown and retained throughout the plant are physically suspended in the flowing sewage at sometime during the process. The opportunity exists for this sludge to wash over the effluent weirs of the plant, thereby exerting excessively large BOD and suspended solids loadings on the receiving waters. In this event, treatment efficiency may be drastically altered. Because of these possibilities the following tests are required as minimum for activated sludge plants according to the schedules on the preceding pages.

SLUDGE VOLUME INDEX (SVI)

1. **Definition.** The SVI is the volume in milliliters occupied by 1 gram of activated sludge after the aerated liquor has settled for 30 minutes.

2. **Significance.** The SVI indicates the bulkiness of the aerated sludge. Since there is no universal SVI each plant must develop experience with its indexes. Changes in the SVI or the SVI Trend established for a particular plant would indicate changes in the sludge characteristics. Changes would deserve intense consideration.

3. **Procedure.**

A. One liter of aerated liquor taken from the outlet of the aeration tanks is allowed to settle in a 1000 mil graduate cylinder for 30 minutes.

B. The sample is thoroughly mixed and suspended solids are run according to one of the methods listed on page 178 and reported as mg/l.

C. $$\text{SVI} = \frac{\text{mils settled sludge} \times 1000}{\text{mg/l suspended solids}}$$

THIRTY-MINUTE SETTLEABILITY

1. **Definition.** The thirty-minute settleability is the volume occupied by the activated sludge after allowing a 1 liter sample of mixed liquor to settle for 30 minutes.

2. **Significance.** The thirty-minute settleability indicates the settling characteristics of the sludge. After the initial solids buildup resulting from startup operations gross changes in 30-minute settleability volume would deserve intense consideration.

3. **Procedure.** Follow step A of the sludge volume index procedure.

LOADING INDEX

1. **Definition.** The loading index is defined as the pounds of 5-day, 20°C BOD added per day to each pound of mixed liquor volatile suspended solids in the aeration tank.

2. **Significance.** The plant must develop a history of indexes to determine its optimum loading index. Recirculation rates may be altered to maintain this optimum feed rate.

3. **Procedure.** The loading index is a simple computation. The 5-day, 20°C BOD entering the aerators from the primary treatment (if present) is calculated in pounds. This figure is divided by the number of pounds of mixed liquor volatile suspended solids resulting in a figure having the following units:

$$\frac{\text{lbs. 5-day, 20°C BOD/day}}{\text{lb. MLVSS in aerator}}$$

TESTS ON DIGESTERS

pH (SLUDGE)

1. **Definition.** pH is a measure of acidity of the sample. pH = 7 is neutral, pH less than 7 is acid, more than 7 is basic. (pH: the negative logarithm of the hydrogen ion concentration.)

2. **Significance.** The critical step of converting sludge breakdown by-products to methane is performed by a group of bacteria called "methane formers" which do not function optunally at lower pH's.

3. **Procedure.**

A. Fill a beaker with sludge to be tested.

B. Cut off approximately 6" of Dializer tubing and tie off one end. Fill with distilled water and suspend in the beaker containing the sludge.

C. After 15 minutes' contact time, wash the sludge from the tubing and run the pH test as outlined on page 174 on the water in the tube.

VOLATILE ACIDS (VA)

1. **Definition.** The volatile acid concentration in the digesting sludge.

2. **Significance.** The VA concentration of the sludge is a characteristic of a particular digester. Changes in the volatile acid trend established for a plant deserve intense consideration. Sudden buildup of a VA indicates a failing system.

3. **Procedure.**

A. Steam Distillation Method. See Standard Methods for procedure.

B. Distillation Method. This method is quite empirical and should be carried out exactly as described. It is not intended for accurate work but satisfactorily serves the purpose of digester control. Method outlined in Item A above should be used for accurate determination.

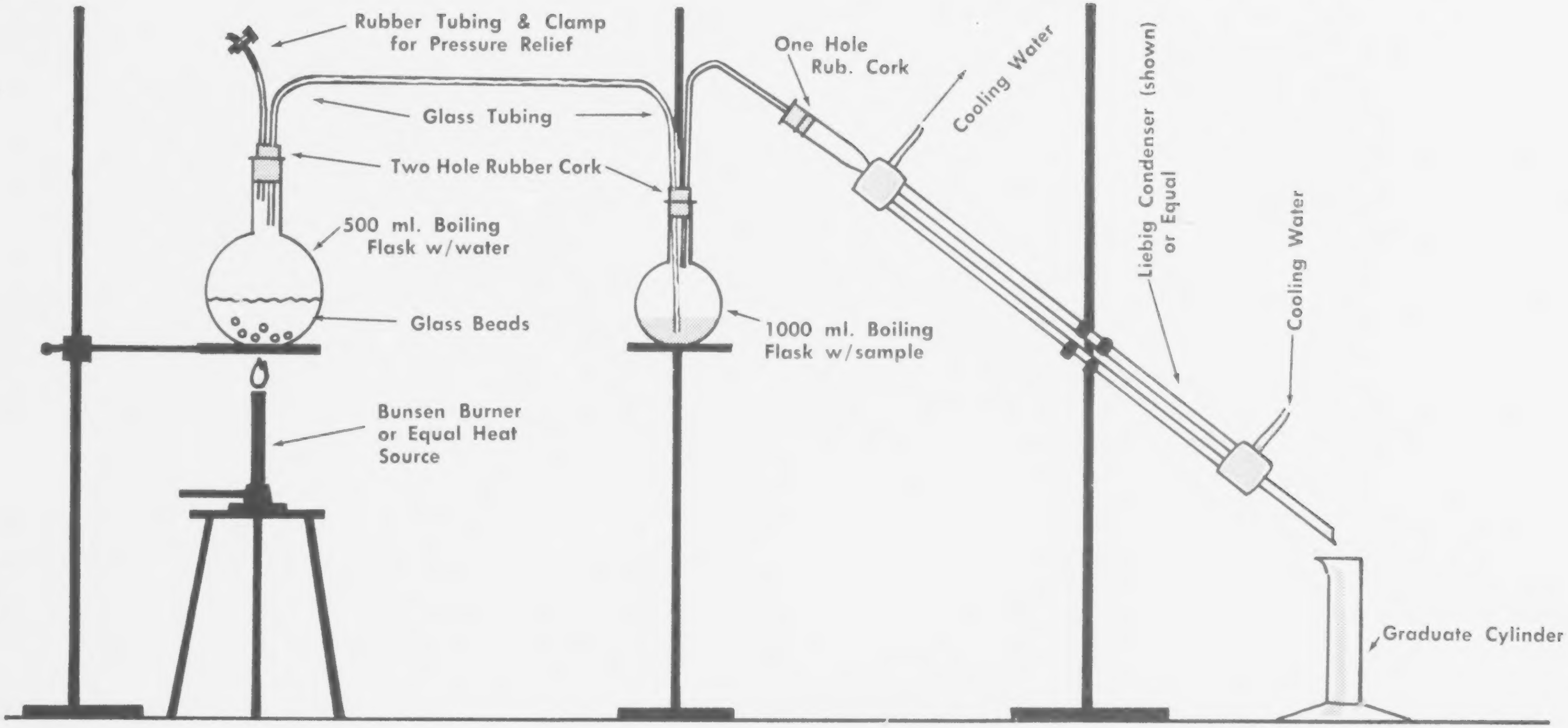
(1) Centrifuge 200 ml of sample for 5 minutes or allow the sludge sample to settle for approximately one-half hour.

(2) Pour off 100 ml of the supernatant liquor in a 500 ml distillation flask.

(3) Add 100 ml of water and 4-5 clay chips or similar material to prevent lumping and 5 ml concentrated sulfuric acid (H_2SO_4), then mix.

(4) Distill off 150 ml at a rate of 5 ml/minute.

(5) Titrate with 0.117 N sodium hydroxide (12), using 4-6 drops of phenolphthalein as an indicator.


Rubber Tubing & Clamp for Pressure Relief
One Hole Rub. Cork
Cooling Water
Glass Tubing
Two Hole Rubber Cork
Liebig Condenser (shown) or Equal
500 ml. Boiling Flask w/water
Cooling Water
Glass Beads
1000 ml. Boiling Flask w/sample
Bunsen Burner or Equal Heat Source
Graduate Cylinder

VOLATILE ACIDS SET-UP WITH STEAM GENERATOR

NOTE:

The diagram shows the Volatile Acids setup with a steam generator. This method will give more consistent results as the temperature of the sample remains constant and the rate of distillation is then controlled by the rate at which the steam is produced. The alternate method would be to eliminate the steam generator and apply heat directly to the sample flask.

(6) Titrate to the first general appearance of the pink color.

Volatile Acids = ml sodium hydroxide x 100.

SLUDGE ALKALINITY

1. **Definition.** The concentration of acid neutralizing material contained in the sludge.

2. **Significance.** The alkalinity of the sludge is a characteristic of a particular digester. Changes in the alkalinity trend established for a plant deserve intense consideration.

3. **Procedure.**

A. Collect sludge sample and allow to settle sufficiently to obtain 20-25 ml clear supernatant. (Should be fairly transparent.)

B. Place 3-4 drops of methyl orange indicator in each of two evaporating dishes. (One is a blank.)

C. Place 10 ml of sample in each dish.

D. Titrate with 0.02 N Sulfuric Acid (H_2SO_4) (11) in one dish comparing color with blank. First change of color to slight pink cast is end point.

E. 1 ml 0.02 N Sulfuric Acid (H_2SO_4) = 100 ppm of Alkalinity ($CaCO_3$).

Alternate Method:

In some cases, a clear supernatant cannot be obtained. Then it will be necessary to dilute and wash sample with distilled water.

For Example

A. Place 20 ml of sample and 80 ml distilled water in closed vessel and shake violently to thoroughly wash sludge solids.

B. Allow to settle and draw off 50 ml.

C. Titrate as above or use Erlenmeyer flask.

D. 50 ml mixture equivalent to 10 ml sample.

E. Alkalinity = ml acid x 100.

pH Meter Method

A. Place a 50 ml sludge sample in a beaker. Rinse out the graduate cylinder used to measure the sample with distilled water.

B. Place the electrodes into the sample.

C. Titrate with 0.02 N Sulfuric Acid until the pH drops to 4.5. This is the end point which is the same as the methyl orange end point given above.

D. Record the amount of acid that was used.

E. Alkalinity = ml acid x 20.

SLUDGE SOLIDS

1. **Definition.** All the material remaining in a sample after the water has been evaporated is considered as the total solids.

2. **Significance.** This test determines the total amount of solids by weight in a sample.

3. **Description of Test.** The test for total solids is carried out by taking a measured amount of sample and placing it in a dish. The water in the dish is driven off by gentle heat. The amount of solids remaining are the total solids.

4. **Procedure.**

A. Place clean evaporating dish in drying oven at 103° for one hour.

B. Cool dish in desiccator and then weigh.

C. Place dish on steam bath.

D. Measure out 100 ml of well mixed sample in 100 ml graduate cylinder.

E. Carefully pour sample into dish.

F. Rinse cylinder carefully with a small amount of distilled water and pour rinsings into the dish.

G. Evaporate sample on steam bath.

H. When all the water is driven off, place dish in drying oven for one hour at 103°C.

I. Cool dish in desiccator.

J. Weigh dried dish.

5. **Sample Computations.**

A. Record results in laboratory notebook.

Example

Sample	raw sewage
Volume of sample	100 ml
Weight of dish plus solids	30.4380 gm.
Weight of dish	30.3500 gm.
Increase in weight	.0880 gm.

$$\frac{\text{Increase in weight x 1,000,000}}{\text{Volume in sample}} = \text{ppm. total solids}$$

$$\frac{.0880 \text{ x } 1,000,000}{100} = 880 \text{ ppm. total solids}$$

(880 grams total solids per million grams sample = 880 ppm)

VOLATILE SOLIDS

1. **Definition.** The volatile solids are that portion of the total solids which will ignite at 600°C.

2. **Significance.** The volatile solids test is used to determine the efficiency of the digestion process in volatile solids reduction.

3. **Procedure.**

A. Ignite residue from the determination of total solids in an electric muffle furnace at 600°C. for 1 hour.

B. Cool in a desiccator and reweigh to the nearest milligram.

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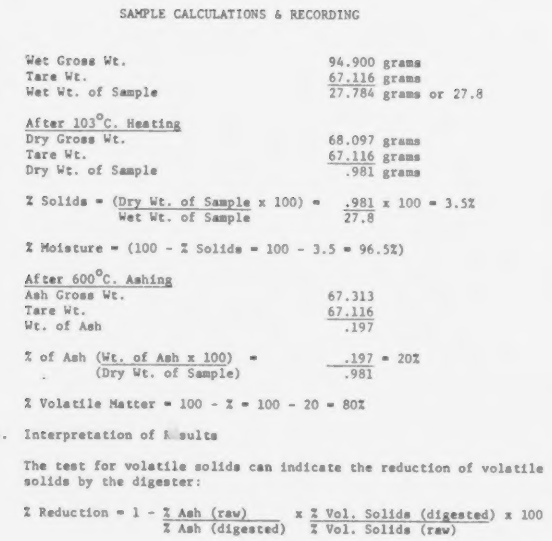


SAMPLE CALCULATIONS & RECORDING

Wet Gross Wt.	94.900 grams
Tare Wt.	67.116 grams
Wet Wt. of Sample	27.784 grams or 27.8

After 103°C. Heating

Dry Gross Wt.	68.097 grams
Tare Wt.	67.116 grams
Dry Wt. of Sample	.981 grams

$$\% \text{ Solids} = \left(\frac{\text{Dry Wt. of Sample}}{\text{Wet Wt. of Sample}} \times 100\right) = \frac{.981}{27.8} \times 100 = 3.5\%$$

% Moisture = (100 - % Solids = 100 - 3.5 = 96.5%)

After 600°C. Ashing

Ash Gross Wt.	67.313
Tare Wt.	67.116
Wt. of Ash	.197

$$\% \text{ of Ash } \frac{(\text{Wt. of Ash} \times 100)}{(\text{Dry Wt. of Sample})} = \frac{.197}{.981} = 20\%$$

% Volatile Matter = 100 - % = 100 - 20 = 80%

4. Interpretation of Results

The test for volatile solids can indicate the reduction of volatile solids by the digester:

$$\% \text{ Reduction} = 1 - \frac{\% \text{ Ash (raw)}}{\% \text{ Ash (digested)}} \times \frac{\% \text{ Vol. Solids (digested)}}{\% \text{ Vol. Solids (raw)}} \times 100$$

Figure 8-35

GAS ANALYSIS

1. **Definition.** The digester gas analysis is the carbon dioxide content of the digester gas expressed in percent.

2. **Significance.** Digester gas production is a direct indication of the activities taking place in a digester. The gas generally analyzes at 30% carbon dioxide and 70% methane. Each plant must develop a history of analysis results. Deviations from the normal trend indicate changes in activities within the digesting sludge. When the operator detects these changes through changing gas analysis, he may perform further and more intensive study of the sludge.

3. **Procedure.**

A. Invert analyzer until all fluid has run into top reservoir volume.

B. Turn analyzer upright until all fluid has run into bottom reservoir volume. All inside surfaces have now been wetted.

C. Hold analyzer upright at 45° angle for 5 full seconds.

D. Hold upright and depress plunger valve at top to vent to atmosphere. Release.

E. Loosen lock nut at rear of scale and slide scale until zero percent CO_2 scale division lines up with the top of the fluid column in the small central bore. Tighten scale lock nut.

F. Insert metal sampling tube into the sample point in the Gas Piping or the digester. Hold the analyzer upright and lay the rubber connector tip on the plunger valve at the top. Depress the plunger valve with the connector tip and squeeze and release the aspirator bulb 18 times. Immediately after the 18th squeeze and before releasing the bulb, release connector tip (plunger valve). Sample is now trapped.

G. Invert the analyzer, place upright and repeat once more. Hold upright at 45° (as in step C above) for 5 seconds and read immediately percent CO_2 on the scale in line with the top of the fluid column in the small central bore. Be sure to depress plunger valve before re-setting to zero for the next sample.

H. Occasionally one should repeat step G (without venting to atmosphere) to check the strength of solution. An increase of more than 1/2% CO_2 in the second reading indicates the solution requires replacement.

Special Note: It is very important to maintain the packing of the filter saturator in the sampling tube in a moist condition.

OPERATION REPORTS

Operation reports are not only intended as a record of the results of laboratory tests, but should include information relating to electrical power consumption; weather conditions; labor, time, or costs; notes on performance of mechanical equipment; and quantities of chemicals or other supplies used. They should indicate as to whether the plant is doing its job and whether or not the operator is doing his job.

Plant operation records may serve as an insurance policy in the event of a pollution complaint against the city by downstream water users. A record of satisfactory operation may relieve the city of liability. Equally important, good plant records are invaluable to the operator in indicating approaching difficulties and possible corrective actions. They are also of great value to the city and the engineer at the time when the plant must be enlarged or replaced.

Sewage Works Report Forms are available from the State Department of Health, 1523 Smith Tower, Seattle, Wn.; Room 304, Public Health Bldg., Olympia, Wn.; 321 Hutton Bldg., Spokane, Wash. When ordering please specify the type and location of the plant.

EQUIPMENT AND SUPPLIES

REAGENTS

1. **Cleaning Solution.** Dissolve about 100 g. of commercial potassium dichromate and 375 ml of

water and make up to 1 liter with concentrated sulfuric acid, or use any good detergent, such as Tide.

2. **Dilution Water.** There are four stock solutions to be prepared by dissolving the chemically pure reagent quality salts in liter quantities of distilled water as follows:

A. Ferric chloride 0.25 g. $FeCl_3.6H_2O$.

B. Calcium chloride 27.5 g. $CaCl_2$ (anhydrous).

C. Magnesium sulfate 22.5 g. $MgSO_4. 7H_2O$.

D. Phosphate buffer solution: Dissolve 8.5 g. KH_2PO_4, 21.75 g. K_2HPO_4, 33.4 g. $Na_2HPO_4.7H_2O$, and 1.7 g. NH_4Cl in about 500 ml distilled water and dilute to 1 liter. The pH of this buffer should be 7.2 without further adjustment.

3. **Standard Dilution Water.** This is prepared by adding to each liter of distilled water 1.0 ml each of ferric chloride solution, calcium chloride solution, magnesium sulfate solution and phosphate buffer solution. This water must be allowed to stand for two weeks uncapped so that the dissolved oxygen in solution will stabilize. By bubbling clean air through the dilution water, one can speed up the time required for stabilization. Add about 1 ml of **fresh settled sewage** to one liter of dilution water for sewage containing industrial wastes. (20 ml to a carboy of dilution water.)

4. **Manganous Sulfate Solution.** Dissolve 480 g. of manganous sulfate $MnSO_4.4H_2O$ or 400 g. of $MnSO_4.2H_2O$ in distilled water. Filter and make up to 1 liter.

5. **Alkaline-Iodide-Sodium Azide.** Weigh out 500 g. of sodium hydroxide NaOH, or 700 g. KOH, 150 g. of potassium iodide KI, or 135 g. NaI, and 10 g. of sodium azide NaN_3. The sodium azide must be dissolved in about 50 ml of distilled water. Mix a solution of sodium hydroxide and potassium iodide and dilute to 950 ml, cool to room temperature and then add slowly the sodium azide (10 g. in 50 ml of water) with constant stirring to avoid local heating. Make up to 1 liter.

CAUTION: Sodium azide should be stored at room temperature or cooler.

6. **Standard Sodium Thiosulfate Solution (.025 N.).** Dissolve 6.205 gms. of sodium thiosulfate ($Na_2S_2O_3.5H_2O$) in freshly boiled and cooled distilled water and dilute to 1 liter. Standard sodium thiosulfate may be preserved by adding 5 ml chloroform or 0.4 gm. sodium hydroxide, NaOH per liter. For accurate determinations, the thiosulfate solution should be standardized.

CAUTION: The STANDARD thiosulfate solution decomposes rapidly and will not remain reliable over long periods; consequently, it should be freshly made up every 6 months. Refrigeration will help considerably in reducing rapid decomposition.

7. **Starch Solution.** Add about 5 or 6 g. of potato starch and stir into a small amount of water. Add about 1.25 g. of salicylic acid if this reagent is available. Pour both the starch and the salicylic acid into 1 liter of boiling water. Stir and let it settle overnight. Pour off the clear supernatant.

8. **Asbestos Fiber Emulsion.** Place about 10 g. of medium fiber, acid-washed asbestos fiber in a liter bottle. Add 900 ml of distilled water and shake thoroughly.

9. **Dilute Sulfuric Acid.** To make 100 ml of 3.6N H_2SO_4 pipette 10 ml of concentrated sulfuric acid into 90 ml of water.

DANGER! Always pour acid into water. Add water to make up to 100 ml on cooling.

10. **Potassium Bi-Iodate Solution.** Stock solution equivalent to 0.1 N thiosulfate contains 3.250 g. $KIO_3.HIO_3$ per liter. A bio-iodate solution equivalent to the 0.025 N thiosulfate solution contains 0.8124 g. of $KIO_3.HIO_3$ per liter and may be prepared by diluting 250 ml of stock bio-iodate solution to 1.0 liter.

Alternate: Potassium dichromate may be substituted for bi-iodate. A solution of potassium dichromate equivalent to 0.025N sodium thiosulfate contains 1.225 g. of $K_2Cr_2O_7$ per liter.

11. **0.02N Sulfuric Acid Solution.** Add 5.55 ml of dilute sulfuric acid and make up to one liter with distilled water.

12. **0.117 N Sodium Hydroxide.** Add 4.67 grams of NaOH, to distilled water and make up to 1 liter.

13. **Methylene Blue Solution.** Dissolve 0.5 grams methylene blue in distilled water and make up to one liter.

NOTE: Preparation of several of the above reagents require exact measurements and are virtually impossible without an analytical balance. The following suggestions are offered as possible solutions to this problem.

1. Often a nearby druggist or High School Chemistry instructor will have the necessary equipment and will be readily willing to give assistance.

2. Several of the chemical supply houses are now selling these solutions ready-made. This is very convenient, however it can be costly if large quantities of reagents are used. See, also, the "Note" in instructions for dissolved oxygen.

STANDARDIZATION PROCEDURE FOR SODIUM THIOSULFATE SOLUTIONS

1. Dissolve approximately 5 g. potassium iodide (free from iodate) in 100 to 150 ml distilled water in Erlenmeyer flask.

2. Add 10 ml of dilute H_2SO_4. (9).

3. Add 40 ml of standard 0.025 N. bi-iodate (or dichromate) solution (10).

4. Set in dark for 5 minutes.

5. Dilute to 200 ml for bi-iodate method or to 400 ml for dichromate method.

6. Titrate with 0.025 N thiosulfate solution, adding 1 to 2 ml starch solution toward end of titration when pale straw color is reached.

7. Exactly 40 ml of thiosulfate should be required when solutions are of equal strength.

Examples of what to do if thiosulfate solution is stronger or weaker:

1. In case solution is stronger than 0.025 N (example only):

If it took only 38.2 ml thiosulfate, multiply results of ppm dissolved oxygen by $\frac{40}{38.2} = 1.05$.

2. In case solution is weak or less than 0.025 N (example only):

If it took 41.2 ml of thiosulfate, multiply results of ppm dissolved oxygen by $\frac{40}{41.2} = 0.97$.

3. Preferred method would be to adjust solution to exactly 0.025 N if solution was made from stock solution of 0.1 N by using equation below:

$$\text{Ml. of stock solution} = \frac{1000 \times \text{desired normality } (0.025)}{\text{Normality of stock solution}}$$

EQUIPMENT AND SUPPLIES

The variability of recommended test as indicated in the previous schedule presents a problem in making up a corresponding list of the required equipment and supplies. In addition another variable is introduced by way of the fact that it is desirable to have more of some pieces of equipment as the plants become larger.

The table on the following pages take these variables into account and permits the selection of a minimum of equipment and supplies to perform the tests as given in the Testing Schedule.

The sewage treatment plants have been organized into three groups:

Column I: Primary Plants over 100,000
Single and Two-Stage Filtration, and Activated Sludge Plants over 20,000
Sewage Lagoons over 5,000
Column II: Primary plants less than 100,000
Column III: All other treatment plants

The "Column" designation is to be used in conjunction with the following list of laboratory supplies. The first three columns on the following pages refer to the type and size of plant as noted above and indicate the number of units of the particular piece of equipment needed.

Many extra frills and added features of accuracy and convenience can be obtained at added cost in the laboratory equipment field. These were purposely avoided in preparing the following list. Consideration was given to the desired minimum accuracy of the tests and convenience to the operator. (List is given on following pages.)

In using the following list of laboratory equipment, the following should be kept in mind: There are several suppliers of this type of equipment throughout the country from whom it may be ordered. Each manufacturer has his own description of more or less identical pieces of equipment. In addition, he has certain pieces of equipment available from his warehouses only.

Column 1	Column 2	Column 3		
				pH
1				pH Meter, 7" Mirrored scale capable of operating either from AC line or internal batteries, Readable to ± .02 pH Fisher 210
1	1	1		Universal Comparitor with magnifying prism eyepiece. Delta 400 P
1	1	1		Bromthymol Blue test kit with glass color standards for comparitor above; 100 tests.
1	1	1		Cresol Red test kit with glass color standards for above; 100 tests.
				SETTLEABLE SOLIDS
*				Imhoff Cones, pyrex
				CHLORINE RESIDUAL
1	1	1		Chlorine and OTA test outfit with glass color standards to be used with same comparitor as used for pH; 200 tests.
				RELATIVE STABILITY
		1		Methylene Blue solution, 16 oz.
		12		Bottles BOD
				TEMPERATURE TESTING
2	1	1		Thermometer −20/110°C x 1°
2	1	1		Thermometer 20/110°C and 0/230°F
				30 MINUTE SETTLEABILITY
		1		Graduated Cylinder pyrex, 1000 ml
				DISSOLVED OXYGEN – Note (1)
24	24	24		BOD Bottles 1-24
24				BOD Bottles 25-48
12	4	4		Pipettes serological, 2 ml
12	4	4		Pipettes serological, 5 ml
12	4	4		Pipettes serological, 10 ml
2	1	1		Pipettes volumetric, 100 ml
4	2	2		Beakers pyrex, griffin type 1000 ml
2	1	1		Beakers pyrex, griffin type 600 ml
2	1	1		Beakers pyrex, griffin type 400 ml
2	1	1		Beakers pyrex, griffin type 250 ml
2	1	1		Burette Support, double, castalloy white base
2	2	2		Erlenmeyer Flask, pyrex, 500 ml
12	12	12		Bottles, glass, 1000 ml
12	6	6		Bottles, glass, 500 ml
1	1	1		Corks assorted
4	2	2		Stopper, 2 hole
1	1	1		Cork borers wing handle, 1-6
4	2	2		Funnels 75mm, short
1	1	1		Funnels 16 oz.
1				Funnels 64 oz.

DISSOLVED OXYGEN (cont.)

Column 1	Column 2	Column 3		
2	1	1		Cylinders, graduated, 1000 ml
1	1	1		Cylinders, graduated, 500 ml
2	2	2		Cylinders, graduated, 250 ml
1	1	1		Support 4 x 6 with rod
2	2	2		Rings, iron with clamp
2	1	1		Rubber stoppers, assorted 1-6, 1 lb.
1	1	1		Rubber stoppers No. 6, 1 lb.
2	1	1		Volumetric Flask, 1000 ml
4	2	2		Wash bottle, 500 ml
4	2	2		Spatulas 3", S.S.
1	1	1		Electric Still, Barnstead ½ gal. with low water cutoff. Note (2)

ALTERNATE FOR SMALL PLANTS:

Column 1	Column 2	Column 3		
	2	2		Filter Ion, 10 gal. capacity
1	1	1		Tripod, 5"
4	2	2		Wire Gauze, asb. center 6" x 6"
1	1	1		Triple beam balance, 2600 gm.
1	1	1		Burner natural gas, Fisher
7	1	1		Chloroform, AR, lb.
1				Copper sulfate AR, crystal, lb.
5	5	5		Manganous Sulfate
1	1	1		Potassium Dichromate
3	1	2		Potassium Iodide
1	1	1		Salicylic Acid, ¼ lb.
2	1	1		Sodium Azide, ¼ lb.
10	2	5		Sodium Hydroxide pellets
2	1	1		Sodium Thiosulfate
4	1	1		Starch, Potato
2	1	1		Sulfuric Acid, 1 x 9 lbs.
1	1	1		Stopcock Grease

BIOCHEMICAL OXYGEN DEMAND (BOD)

All items necessary for the Dissolved Oxygen Test are needed, plus the following:

Column 1	Column 2	Column 3		
1	1	1		Glass Tubing 7 mm, 1 lb.
1	1	1		Glass Rod 6 mm, 1 lb.
1				Incubator BOD with internal 115 v outlet
	1	1		Incubator Thelco 2
1	1	1		Refrigerator 3 cubic ft. Note (3)
2	1	1		Rubber Tubing 50', ¼" x 1/16" wall
6	2	2		Pinch clamps, small
4	2	2		Carboys, 5 gallon, polyethylene
1	1	1		File 4" triangular
1	1	1		Ammonium Chloride, lb.
1	1	1		Calcium Chloride, Anhyd. 12 mesh, lb.
1	1	1		Ferric Chloride, lb.
1	1	1		Iodine, USP, ¼ lb.

Column 1	Column 2	Column 3		
				BIOCHEMICAL OXYGEN DEMAND (BOD) (cont.)
1	1	1		Magnesium Sulfate
1	1	1		Potassium Phosphate Monobasic (KH_2PO4)
1	1	1		Potassium Phosphate Dibasic (K_2HPO4)
1	1	1		Sodium Phosphate Dibasic $(Na_2HPO4.7H_2O)$
				TOTAL SOLIDS TEST
	1	1		Analytical balance 160/220 gram capacity 0.1 mg sensitivity Note (4)
1				Analytical balance 160 gram capacity 0.1 mg sensitivity, single pan Mettler H6D
	1	1		Set Weights 5 mg – 1000 g. S-1 Note (4)
	1	1		Balance Pan glasses counter poised, pair, Note (4)
1				Water Bath, electric
1				Cover for above, 8 hole
12	2	2		Evaporating Dishes No. 2
6	2	2		Evaporating Dishes No. 00A
1	1	1		Evaporating Oven, 12 x 12 x 12
1	1	1		Desiccator Pyrex, 250 mm
1	1	1		Desiccator Plate No. 5, 230 mm
2	1	1		Tongs 9" Steel
				VOLATILE SOLIDS TEST
1				Muffle Furnace medium, complete with stepless controller and Pyrometer
	1	1		Muffle Furnace small, complete with stepless controller and Pyrometer
				SUSPENDED SOLIDS TEST
6	2	4		Crucibles Gooch No. 3
6	2	4		Crucibles Gooch, fritted disc
2	1	1		Crucible holder, Walter
2	1	1		Crucible holder, 32 mm
6	2	2		Flasks suction, 500 ml
2	1	1		Filter Pump 3/8"
1	1	1		Tubing rubber 1/4 x 3/16, 5'
2	1	1		Asbestos, medium fibre, acid washed
2	2	2		Triangles pipe stem 2"
				SLUDGE ALKALINITY
4	2	2		Dropping bottles, 60 ml, ground glass pipette
1	1	1		Methyl Orange Soln. 4 oz.
1	1	1		Phenolphthalein Soln. 4 oz.
1	1	1		Clamp, castalloy, utility
1	1	1		Burette, 50 ml x 0.1
2	2	2		Dish Evaporating, 90 ml
2	2	2		Flask Erlenmeyer, 250 ml, pyrex

Column 1	Column 2	Column 3		
				VOLATILE ACIDS
1	1	1		Boiling Flask, ring neck, 1000 ml
1	1	1		Boiling Flask, ring neck, 500 ml
1	1	1		Condenser, Liebig, 600 mm
1	1	1		Adapter medium
				SLUDGE VOLUME INDEX (SVI)
1		1		Cylinder Graduated pyrex, 1000 ml
				GAS ANALYSIS
1	1	1		Carbon Dioxide Analyzer. Portable type complete range 0-60%
1	1	1		Carton of 3, CO_2 fluid, KOH soln.

NOTES:

1. There are several instruments now on the market which will read Dissolved Oxygen directly under controlled conditions. These must be calibrated by chemical methods, however, if a great many tests are to be run, it might be wise to investigate the purchase of portable units or continuous monitors. One may consult the local laboratory supply house for information.

2. It is highly recommended that if a still is purchased, it be equipped with a low water cut-off. This will prevent burning out the unit if the water supply is shut off. If a still is purchased without the cut-off, the catalog reference should be changed to 26112-021.

3. It will many times be found much less expensive to purchase a small household type refrigerator (8-9 cu. ft.) from an appliance dealer in your area.

4. Although the price is considerably higher ($670 vs. approximately $225) in the long run the single pan, Mettler balance should prove more economical. It does not require a skilled operator and is almost mistake proof. It is virtually trouble free and regular service is available, if trouble occurs. Weights and weighing glasses are not required.

CHAPTER IX

FUNDAMENTALS

MATHEMATICS

1. **Introduction.** Mathematics deals only with one thing–reasoning leading to proof. Man is a reasoning animal and can best express his thoughts in the language of mathematics. Many people, however, are afraid of this language and studiously avoid becoming involved in the manipulation of numbers. All basic ideas can be expressed in simple words and phrases, but it is clearer and takes less time to translate the words and phrases into the shorthand of mathematics. The shorthand language is simpler than most other languages because it involves only numbers and a few symbols. In the arabic system which we use, there are only ten basic numbers which can be grouped to make a counting and calculation system: 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9. The language of numbers is one of the first learned in school. It becomes so much a part of each person that it is forgotten as a basic concept and a language. The more difficult part comes with trying to put the numbers together in a form that leads to an answer to a problem.

2. **Numbers and Counting.** The ten numbers are put together into an order such that each succeeding number is one larger than the one behind it. Table 9-1 illustrates the order of numbers and method of counting to 100 which we generally take for granted:

TABLE 9-1
Numbers

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100

Of course this can be carried on and on in steps of one to any number that is desired. The system has value because it is used as the basis for the manipulation of numbers in addition, subtraction, multiplication and division. Just as we must crawl before we walk, we must learn to count before we do arithmetic.

3. **Expression of Numbers and Symbols.** Numbers can be expressed in many ways in addition to the counting technique described. For example, if we have a pie and cut it into four parts, we call each piece a fraction consisting of one-fourth (1/4) of the pie or we say that the pie is one hundred percent so that each of the four pieces is twenty-five percent (25%) of the entire pie. The pie may be also considered as one hundred units and each piece then will be a fraction of the pie, or 25 units (usually expressed as a decimal written as 0.25). The decimal system is partially illustrated in Table 9-2 with regard to placement of the decimal point:

TABLE 9-2

PLACEMENT OF THE DECIMAL POINT

6 zeros	1,000,000.	one million
5 zeros	100,000.	one hundred thousand
4 zeros	10,000.	ten thousand
3 zeros	1,000.	one thousand
2 zeros	100.	one hundred
1 zero	10.	ten
	1.	one
1 place	0.1	one tenth
2 places	0.01	one hundredth
3 places	0.001	one thousandth
4 places	0.0001	one ten thousandth
5 places	0.00001	one hundred thousandth
6 places	0.000001	one millionth

Signs and symbols are also important in expressing number relationships. Part of these signs and symbols will be pointed out as they are used. For purposes of this manual, an expression of addition such as two plus three equals five will be written, 2 + 3 = 5. Subtraction of seven minus four equals three will be written, 7 – 4 = 3. Multiplication of four times eight equals thirty-two will be written either as 4 x 8 = 32 or (4) (8) = 32. Division of twenty-four divided by three equals eight will be written as 24/3 = 8, $3\overline{)24}$ = 8 or 24 ÷ 3 = 8.

4. **Manipulation of Numbers.**

A. Addition and Subtraction. As noted previously, numbers are the shorthand of mathematics. They are only good if they are used. It was pointed out that, in counting, each succeeding number was one more than the number behind it. This is the basis for addition and subtraction. For example, referring to Table 9-1, if we wanted to add 6 to 45 we merely have to progress 6 numbers to 51; or if we want to subtract 12 from 47, we back off 12 numbers to 35. This process is too time consuming for everyday use, so we just memorize so addition and subtraction becomes a habit.

B. Multiplication. Multiplication is also addition, but the process becomes too long-winded for common use, so that again we turn to memorizing times tables. Table 9-3 demonstrates the combinations that are profitable to learn. The darkened areas of the table show the relationship between addition and multiplication. Going across on line 7, it is noted that each succeeding number increases by 7.

TABLE 9-3

MULTIPLICATION

Multiply by	1	1	2	3	4	5	6	7	8	9	10	11	12
	2	2	4	6	8	10	12	14	16	18	20	22	24
	3	3	6	9	12	15	18	21	24	27	30	33	36
	4	4	8	12	16	20	24	28	32	36	40	44	48
	5	5	10	15	20	25	30	35	40	45	50	55	60
	6	6	12	18	24	30	36	42	48	54	60	66	72
	7	7	14	21	28	35	42	49	56	63	70	77	84
	8	8	16	24	32	40	48	56	64	72	80	88	96
	9	9	18	27	36	45	54	63	72	81	90	99	108
	10	10	20	30	40	50	60	70	80	90	100	110	120
	11	11	22	33	44	55	66	77	88	99	110	121	132
	12	12	24	36	48	60	72	84	96	108	120	132	144

Down on line 4 each number increases by 4. Essentially it is just another counting system similar to Table 9-1. For longer numbers such as 473 times 342 the procedure is somewhat more complex, but essentially uses Table 9-3 as a basis.

```
    473
  x 342
    946          Multiple 2 x 473 = 946
   1892          Shift 1 digit to left, multiply 4 x 473 = 1892
  1419           Shift 1 digit to left, multiple 3 x 473 = 1419
 161766          Add to get answer
```

Note that in multiplying 4 x 473 there are numbers to carry, as follows:

```
 +2+1

  473            Step 1    4 x 3 = 12
  x 4            Step 2    Write down the 2 and carry the 1
 1892            Step 3    4 x 7 = 28, add 1 = 29
                 Step 4    Write down the 9 and carry the 2
                 Step 5    4 x 4 = 16, add 2 = 18
                 Step 6    Write down the 18
```

C. Division. Division is the reverse of multiplication and uses the same figures of Table 9-3 as the base. For example: 121/11=11 and 28/7=4. Let us take the example given in the multiplication section to illustrate the procedure of so-called long division.

```
       473        Step 1    342 will go into 1617 about 4 times.
342/161766                  Put 4 above 7
    1368          Step 2    Multiple 4 x 342 = 1368
     2496         Step 3    Subtract 1368 from 1617
     2394         Step 4    Bring the 6 down from above and find
      1026                  the number of times 342 will go into
      1026                  2496 (7 appears to fit)
                  Step 5    Multiply 7 x 342 = 2394
                  Step 6    Subtract 2394 from 2496
                  Step 7    342 will go into 1026 3 times.
                            Put 3 above 6
                  Step 8    Multiply 3 x 342 to get 1026
```

This shows that division is a reverse of multiplication. In some problems there will not be an even number. The difference is called a remainder.

D. Square Root. The square root of a number is the quantity that can be multiplied by itself to equal the number. There is an arithmetic process for finding the square root.

```
             2  3   9.4 answer
            V5 73 21.72
             2 4
  40    43|  1 73
             1 29
 460  469|     44 21
               44 21
     4784|   2 00 72
             1 91 36
                 9 36
```

(1) From the decimal point split the number into pairs.

(2) Starting with the 5, pick the nearest even number which will equal approx. 5 when multiplied by itself (2 in this case). Multiply 2 x 2 = 4.

(3) Subtract 4 from 5 and bring down the figures 73.

(4) Multiply 2 by 20 to get a trial divisor. 40 will go into 173 about 3 times; put 3 above 73 and in place of the 0 in 40; multiply 3 x 43 = 129; subtract; carry down the figures 21.

(5) Multiply 23 by 20 to get a trial divisor; 460 will go into 4421 about 9 times; put 9 above 21 and in place of the 0 in 460; multiply 9 x 469 = 4221; subtract; carry down the figures 72 and repeat the process.

E. Fractions. A fraction is an expression of an unworked division. It represents a part of a complete system. The terms are the numerator on the top and the denominator on the bottom. Fractions can be added, subtracted, multiplied or divided the same as whole numbers, or they can be combined with whole numbers.

(1) To multiply a fraction by a whole number, multiply the whole number and the numerator and put the product over the same denominator.

$$6 \times \frac{4}{9} = \frac{24}{9} = \frac{8}{3}$$

(2) To multiply a fraction by a fraction, multiply the numerators for the new numerator and the denominators for the new denominator.

$$\frac{3}{5} \times \frac{6}{7} = \frac{18}{35}$$

(3) To divide a whole number by a fraction, invert the fraction and multiply.

$12 \div \frac{4}{7} = 12 \times \frac{7}{4} = \frac{84}{4} = 21$

(4) To divide a fraction by a fraction, multiply the dividend by inverted divisor.

$\frac{2}{3} \div \frac{4}{7} = \frac{2}{3} \times \frac{7}{4} = \frac{14}{12} = \frac{7}{6}$

(5) Only fractions with a common denominator can be added or subtracted.

$\frac{2}{3} + \frac{4}{7} + \frac{5}{9}$ cannot be added as it stands

A common denominator is 63, so the fractions become

$\frac{21(2)}{63} + \frac{9(4)}{63} + \frac{7(5)}{63} = \frac{42+36+35}{63} = \frac{113}{63}$

$\frac{2}{3} - \frac{1}{4}$ cannot be subtracted

12 is a common denominator

and $\frac{2(4)}{12} - \frac{3(1)}{12} = \frac{8-3}{12} = \frac{5}{12}$

(6) If the numerator or denominator of a fraction are multiplied or divided by the same number, the value of the fraction is not changed. This is the principal of cancellation. Adding or subtracting a number from both numerator and denominator does change the value of the fraction. As an example:

$\frac{3}{4} = \frac{3\times2}{4\times2} = \frac{6}{8}$ which is equal to $\frac{3}{4}$

$\frac{3}{4} \neq \frac{3+2}{4+2} = \frac{5}{6}$ $\frac{5}{6}$ does not equal $\frac{3}{4}$

(7) Ratios and proportions are forms of fractions. A ratio expresses the relation of two numbers of the same kind to each other. The ratio of one number to another is indicated by division. Thus, the ratio of 2 to 4 is written 2/4. Other ratios might be 7/12, 8/16, 4/3, 8/24, etc. For example, 1 quart is 1/4 of a gallon. The fraction 1/4 is the ratio which can be expressed as 1/4 or 1:4. When two ratios are equal and are placed equal to each other in an equation, the equality becomes a proportion. Problems with an unknown quantity can be solved by use of proportions. For example, if 3 quarts of water are needed to dilute 1 quart of antifreeze to protect an automobile cooling system, the number of quarts of antifreeze necessary to add to 18 quarts of water to make the same dilution would be?

F. Decimals and Percentage. A fraction of 1/10 can be expressed as 0.1, and a fraction of 1/100 can be expressed as 0.01. These are decimal notations and are often more useful than regular fractions. For example, the fraction $\frac{2742}{4721}$ can be expressed as 0.5808 to the nearest four decimal places (see Table 9-2). Decimal numbers are convenient because they can be added, subtracted, multiplied and divided. Percentages are merely decimal parts of one hundred. That is one percent is one one-hundredth of a unit.

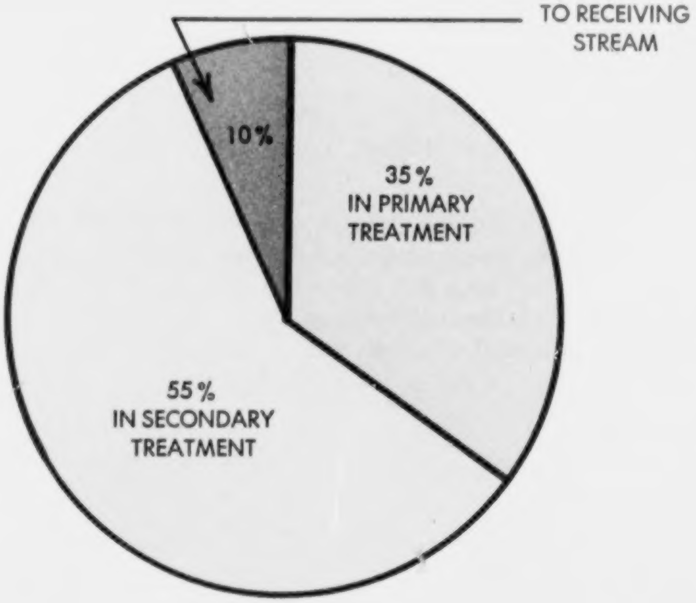
Examples of decimal manipulation are:

```
Addition         Subtraction        Multiplication              Division

(Note that decimal points           (Note that 5 places
 are lined up)                       are pointed off)

  0.127           12.78540             2.357                          0.8576
 40.26542        - 7.93262           x 0.47            0.321 /0.275 3000
187.314            4.85278             16499                     256 8
  1.2015                               9428                       18 50
228.90792                             1.10779                     16 05
                                                                   2 450
                                                                   2 247
                                                                     2030
                                                                     1926
                                                                      104 Remainder
```

Percentage can best be illustrated by a pie chart showing BOD removals of waste where full circle is 100%.



5. **Units and Formulae.**

A. Units of Measurement. Before we can solve mathematical problems, it is necessary that we gain a clear understanding of units of measurement with which we are working. Basically, there are two systems of measurement; namely, (1) the English System and (2) the Metric System. The operator must be familiar with both systems.

Table 9-4 presents a list of conversion factors and illustrates the relationship between the two systems of measurement.

B. Abbreviations. For simplicity, physical units are usually abbreviated when working mathematical problems. It is important that the operator familiarize himself with the abbreviations that he will normally be using. Some of the common ones are:

English System

Unit	Abbreviation
Feet	ft or '
Inches	in or "
Square feet	sq ft or ft^2
Acre	ac
Cubic feet	cu ft or ft^3
Gallons	gal
Cubic feet per second	cfs or cu ft/sec
Gallons per minute	gpm or gal/min
Gallons per hour	gph or gal/hr
Gallons per day	gpd or gal/day
Thousand gallons per day	tgd
Million gallons per day	mgd
Pounds	lb or #
Parts per million	ppm

Metric System

Unit	Abbreviation
Centimeters	cm
Square centimeters	sq cm or cm^2
Cubic centimeters	cu cm or cm^3
Liters	l
Milliliters	ml
Grams	gm
Milligrams	mg
Milligrams per liter	mg/l

The symbol π is a letter of the Greek alphabet, "pi", pronounced as "pie." In mathematics, π is used to denote a constant which is used in solving problems relating to a circle. π is the ratio between the circumference and the diameter of a circle and is equal to $\frac{22}{7}$ or 3.1416. For all practical purposes, we can use 3.14 as the value for π. In some calculations it is convenient to use $\frac{1}{4}\pi$ or $\frac{\pi}{4}$ which has a value of 0.7854, generally 0.785.

C. Use of Units. Units are always divided and multiplied the same as the numbers, but they are not added or subtracted. For example:

$$3 \text{ ft} \times 3 \text{ ft} = 9 \text{ sq ft or } 9 \text{ ft}^2$$

$$9 \text{ ft}/3 \text{ ft} = 3$$

$$3 \text{ ft} + 3 \text{ ft} = 6 \text{ ft}$$

$$3 \text{ ft} - 2 \text{ ft} = 1 \text{ ft}$$

In multiplication, we multiply the units the same as the numbers. Feet times feet is equal to square feet; square feet times feet is equal to cubic feet; feet times pounds is equal to foot pounds, etc.

TABLE 9-4

SELECTED UNITS OF MEASUREMENT

	English System	Metric System
LINEAR		
1 inch (in) (")		= 2.54 centimeters (cm)
1 foot (ft) (')	= 12"	= 30.48 cm
1 yard (yd)	= 36" = 3'	= 91.44 cm
39.37"	= 3.28' = 1.094 yd	= 1 meter (m)
1 mile	= 5280'	= 1.61 kilometers (km)
AREA		
1 square inch (sq in) (in^2)		= 6.45 sq cm
1 square foot (sq ft) (ft^2)	= 144 sq in	
1 square yard (sq yd) (yd^2)	= 9 sq ft	
1 acre (ac)	= 43,560 sq ft	
1 square mile = 640 ac		= 2.59 sq kilometers
VOLUME AND CAPACITY		
1 cubic inch (cu in) (in^3)		= 16.39 cubic centimeters (c.c.)
1 cubic foot (cu ft) (ft^3)	= 1728 cu in = 7.48 gallons	
1 gallon (gal)	= 4 quarts (qt) = 8 pints (pt) = 128 fluid oz	= 3.785 liters (l) 1 liter = 1000 milliliters (ml) = 1000 cubic centimeters (c.c.)
WEIGHT		
1 pound (lb) (#) = 16 ounces (oz)		= 453 grams (gm) = 7000 grains (gr)
2.205 pounds		= 1000 grams = 1 kilogram (kg)
1 cu ft water	= 62.4 lbs	1 liter water = 1000 gm = 1 kg
1 gallon water	= 8.33 lbs	1 milliliter water = 1 gm

RATE OF FLOW

Metric system not generally used. The most common units are:

Gallons per minute	(GPM)
Gallons per hour	(GPH)
Gallons per day	(GPD)
Million gallons per day	(MGD)
Cubic feet per second	(CFS)

1 GPM = 60 GPH
1 GPM = 1440 GPD
1 MGD = 694 GPM = 41440 GPH
1 CFS = 60 CFM = 3600 CFH
= 1440 CFD
= 646,300 GPD = 0.6463 MGD
1 MGD = 1.547 CFS

In division, we cancel units if they are identical (i.e., ft divided by ft, pounds divided by pounds, etc.). However, if we divide pounds by feet, we cannot cancel the units since they are dissimilar and as a result must appear in the answer.

In addition and subtraction, it is important to remember that we can never add or subtract numbers having different units.

Below are some more examples:

(1) multiplication.

$$9 \text{ sq ft} \times 3 \text{ ft} = 27 \text{ cu ft or } 27 \text{ ft}^3$$

$$4 \text{ ft} \times 2 \text{ lb} = 8 \text{ ft lb}$$

(2) division.

$$\frac{9 \text{ sq ft}}{3 \text{ ft}} = \frac{(9)\ (\text{ft})\ (\cancel{\text{ft}})}{3\ \cancel{\text{ft}}} = 3 \text{ ft}$$

(3) addition.

$$9 \text{ lb} + 15 \text{ lb} = 24 \text{ lb}$$

9 ft + 3 gal = not workable, since units are different

(4) subtraction.

$$10 \text{ lb} - 5 \text{ lb} = 5 \text{ lb}$$

9 ft - 3 gal = not workable, since units are different

(5) cancellation of terms. As we have previously seen, units are handled in the same manner as numbers in multiplication and division. By cancelling identical units in a mathematical expression, we can easily determine the units in our answer. Below are some examples:

$$\frac{\text{ft} \times \cancel{\text{lb}}}{\cancel{\text{lb}}} = \text{ft}$$

$$\frac{\text{sq ft} \times \text{ft} \times \text{gal}}{\text{cu ft} \times \text{hr}} = \frac{\cancel{\text{ft}} \times \cancel{\text{ft}} \times \cancel{\text{ft}} \times \text{gal}}{\cancel{\text{ft}} \times \cancel{\text{ft}} \times \cancel{\text{ft}} \times \text{hr}} = \text{gal/hr (gph)}$$

$$\frac{\cancel{\text{gal}}}{\cancel{\text{day}}} \times \frac{\text{cu ft}}{\cancel{\text{gal}}} \times \frac{\cancel{\text{day}}}{\cancel{\text{hr}}} \times \frac{\cancel{\text{hr}}}{\cancel{\text{min}}} \times \frac{\cancel{\text{min}}}{\text{sec}} = \text{cu ft/sec or cfs}$$

One item which may be confusing in cancellation of terms is the method of denoting units below the division sign. Say that we wish to convert 72 sq in to sq ft. We find from Table 9-4 that there are 144 sq in per sq ft or 144 in/sq ft.

We set up our equation as:

$$\text{No. of sq ft} = \frac{72 \text{ sq in}}{144 \text{ sq in/sq ft}}$$

Note the position of "sq ft" below the division line. When a term falls in this position, we simply move it to the top of the division line.

$$\text{Thus: No. of sq ft} = 72 \text{ sq in} \times \frac{\text{sq ft}}{144 \text{ sq in}}$$

$$\text{Or: } \frac{72 \text{ sq in}}{144 \text{ sq in/sq ft}} = 72 \text{ sq in} \times \frac{\text{sq ft}}{144 \text{ sq in}}$$

Our final answer is 0.5 sq ft

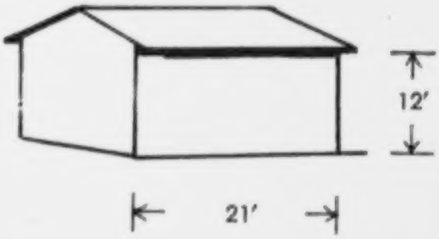
D. Formulas. The use of formulas in mathematics is of vital importance because most problems lend themselves to solution by formula. It is important to be able to state the problem in words first, convert those words to mathematical shorthand and then put in units and numbers to get the answer.

To illustrate the above procedure, consider the side of a shed which needs siding. It is desired to know how many square feet are needed. The problem may be set up as follows:

GIVEN: The building side is 21 feet by 12 feet.

REQUIRED: The number of square feet of siding to cover the wall.

Sketch:



Solution: The area of the side is equal to the length times the width. Written in mathematical terms, this statement becomes

Area = Length x Width
or A = L x W

Now numbers can be put into the equation

and A = 21 ft x 12 ft
= 252 square feet, usually written ft^2

The equation which was just derived is the general one for the area of a rectangle. Look at it again in simplified form. The rectangle below has sides of 5 ft and 4 ft. The area is defined as length times width ($A = LW = 5 \times 4 = 20\ Ft^2$). It can be seen from the diagram that there are indeed 20 squares of 1 ft by 1 ft.

1	2	3	4	5
10	9	8	7	6
11	12	13	14	15
20	19	18	17	16

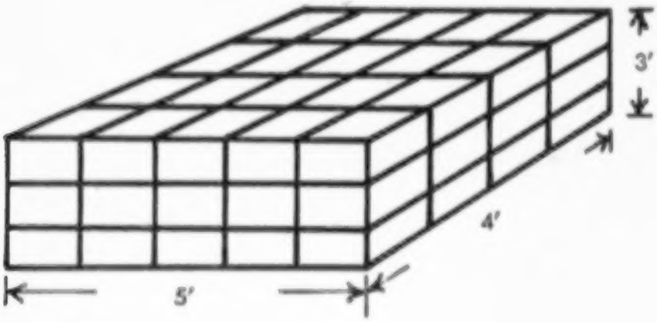
4 ft

5 ft

Now look further at another dimension. Suppose it is desired to find the volume of a box, tank or concrete form in cubic feet. The general equation that is given for volume is volume equals length times width times depth or height. Put into mathematical shorthand this becomes:

$$V = LWH$$

Look at the illustration below as the base for a box. Let the box be three feet deep.



It can be seen that the volume is obtained by counting the total number of 1 cubic foot blocks in the box. We saw that there were 20 in each layer. There are three layers, so that the equation for volume is

$$\begin{aligned} V &= L \times W \times H \\ &= 5 \text{ ft} \times 4 \text{ ft} \times 3 \text{ ft} \\ &= 60 \text{ cubic feet (usually written ft}^3) \end{aligned}$$

Other areas and volumes that are commonly used in this field are shown in Tables 9-5 and 9-6.

E. Example Problems.

(1) Problem: How many acres does a plant site 400 ft by 600 ft contain?

Solution: Area = length x width

$A = 400 \times 600 = 240{,}000$ sq ft

1 ac = 43560 sq ft

Therefore, $A = \dfrac{240{,}000 \cancel{\text{sq ft}}}{43560 \cancel{\text{sq ft}}/\text{ac}} = \underline{\underline{5.51 \text{ ac}}}$

(2) Problem: What is the area of a 6-inch pump piston?

Solution: $A = \dfrac{\pi d^2}{4} = \dfrac{\pi (6 \text{ in})\ (6 \text{ in})}{4} = \underline{\underline{28.3 \text{ sq in}}}$

(3) Problem: Find the cross-sectional area of an 8-inch sewer pipe.

Solution: $A = \dfrac{\pi d^2}{4} = \dfrac{\pi (8 \text{ in})\ (8 \text{ in})}{4} = \underline{\underline{50.2 \text{ sq in}}}$

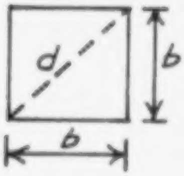
TABLE 9-5

AREA FORMULAS (Two-dimensional - area always in square units.)

Square:

Area = (b) (h) $= b^2$

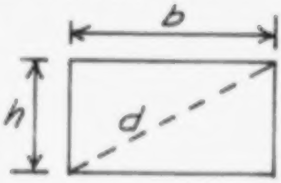
d = (b) $\sqrt{2}$ = 1.414(b)



Rectangle:

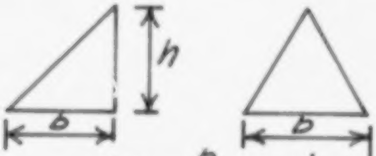
Area = (b) (h)

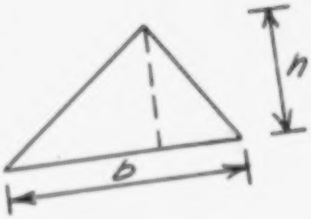
d = $\sqrt{b^2 + h^2}$



Triangle:

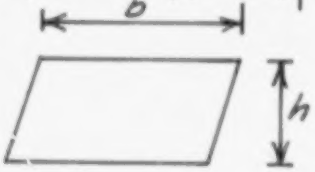
Area = $\frac{(b)\ (h)}{2}$





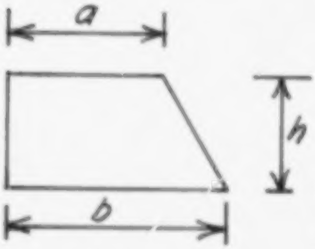
Parallelogram:

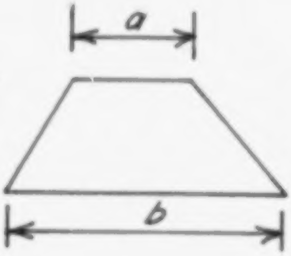
Area = (b) (h)



Trapezoid:

Area = $\frac{h(a + b)}{2}$

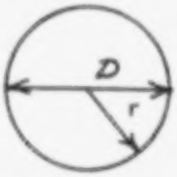




Circle:

Area = $\pi R^2 = \frac{\pi D^2}{4}$

= 3.1416 R^2



R = RADIUS
D = DIAMETER
C = CIRCUMFERENCE
C/D = π = 3.1416

TABLE 9-6

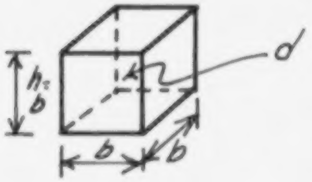
VOLUME FORMULAS (Three-dimensional - volume always in cubic units.)

Cube:

Volume $= (b)\,(b)\,(h) = b^3$

d $= b\sqrt{3} = 1.732\,(b)$

Surface $= 6\,(b^2)$

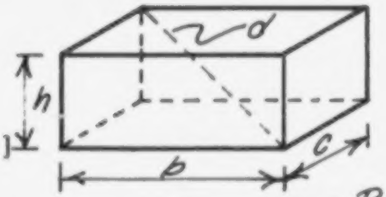


Rectangular Parallelopiped:

Volume $= (b)\,(c)\,(h)$

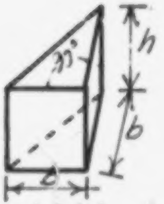
d $= \sqrt{b^2 + c^2 + h^2}$

Surface $= 2[(b)\,(h) + (c)\,(h) + (b)\,(c)]$

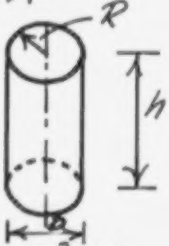


Prism or Cylinder:

Volume = (base area) (height)



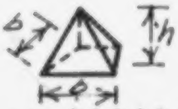
$V = \frac{(b)(b)}{2}\,(h)$



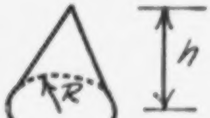
$V = \pi R^2\,(h)$
$= 3.1416\,R^2\,(h)$

Pyramid or Cone:

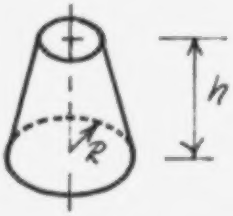
Volume = 1/3 (base area) (height)



$V = 1/3\,(b)(b)(h)$



$V = 1/3\,\pi R^2\,(h)$



Frustrum of Pyramid or Cone:

Volume $= (A_1 + A_2 + \sqrt{A_1 \times A_2})\,h/3$

A_1 and A_2 = Area base and top

(4) Problem: Find the surface area of a 60 ft diameter trickling filter in sq ft; in acres.

Solution: $A = \frac{\pi d^2}{4} = \frac{\pi \times 60 \text{ ft} \times 60 \text{ ft}}{4} = \underline{\underline{2830 \text{ sq ft}}}$

$A = \underline{\underline{2830 \text{ sq ft}}}$

One acre is equivalent to 43,560 sq ft

Therefore, acres = $\frac{\text{no. of sq ft}}{43560}$

Therefore, $A - \frac{2830 \cancel{\text{sq ft}}}{43560 \cancel{\text{sq ft}}/\text{ac}} = \underline{\underline{0.065 \text{ ac}}}$

(5) Problem: Find the volume of a rectangular clarifier 40 ft x 20 ft x 10 ft deep. Express the capacity in cu ft; in gallons.

Solution: The volume of a rectangular clarifier is equal to the area x depth or equal to the length x width x depth.

$V = (40 \text{ ft})(20 \text{ ft})(10 \text{ ft}) = \underline{\underline{8000 \text{ cu ft}}}$

1 cu ft = 7.48 gal, or for all practical purposes, equal to 7.5 gal.

Therefore, $V = 8000 \text{ cu ft} \times \frac{7.5 \text{ gal}}{\text{cu ft}}$

V = 60,000 gal

(6) Problem: Find the area of a rectangular clarifier 20 ft wide by 40 ft.

Solution: Area of a rectangle = length x width, or from Reference Sheet 9-2,

$A = bh = 20 \text{ ft} \times 40 \text{ ft} = \underline{\underline{800 \text{ sq ft}}}$

(7) Problem: Find the volume of a 40 ft diameter clarifier which is 5 ft in depth. Give the answer in cu ft and in gallons.

Solution: The volume of a circular clarified (cylinder)

is equal to the area x depth or equal to $\frac{\pi d^2 h}{4}$

$V = \frac{\pi(40 \text{ ft})(40 \text{ ft})(5 \text{ ft})}{4} = \underline{\underline{6300 \text{ cu ft}}}$

1 cu ft = 7.5 gal

Therefore, $V = 6300\ \cancel{cu\ ft} \times \frac{7.5\ gal}{\cancel{cu\ ft}}$

$$\underline{V = 47250\ gal}$$

(8) Problem: 1000 ft of 8-inch sewer is standing full of sewage. Calculate the gallons of sewage in the line.

Solution: From a previous problem, we found that the area of an 8-inch pipe was 50.2 sq in. The pipe volume is equal to the area times length, or V = A x L.

Convert the pipe area to sq ft.
1 sq ft = 144 sq in

Therefore, $A = \frac{50.2\ \cancel{sq\ in}}{144\ \cancel{sq\ in}/sq\ ft} = 0.349\ sq\ ft$

$$V = (0.349\ sq\ ft)\ (1000\ ft)$$

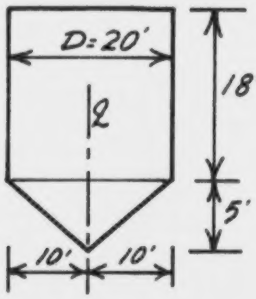
$$V = 349\ cu\ ft$$

$$1\ cu\ ft = 7.5\ gal$$

$$V = 349\ \cancel{cu\ ft} \times \frac{7.5\ gal}{\cancel{cu\ ft}}$$

$$\underline{V = 2610\ gal}$$

(9) Problem: Compute the volume of a circular digester (in cu ft and in gallons) having the following dimensions:



Solution: Essentially, the upper 18 feet is a cylinder, and the 5 ft hopper constitutes a cone. Therefore, the total volume is equal to the volume of the cylinder plus the volume of the cone.

V (cylinder) = πr^2 (h) = π(10 ft)(10 ft)(18 ft) =
5650 cu ft

V (cone) = 1/3 πr^2 (h) = $\frac{\pi(10 \text{ ft})(10 \text{ ft})(5 \text{ ft})}{3}$ =
523 cu ft

V (digester) = 6173 cu ft

or V (digester) = (6173 cu ft)(7.5 gal/cu ft)

= 46100 gal

(10) Problem: Determine the (1) cubic feet and (2) acre feet of filter rock in a 60-foot diameter filter with a rock depth of 4 ft.

Solution: From a previous problem (8 e), we found that the area of a 60-foot filter was 2830 sq ft, or 0.065 ac.

a. Rock volume = (2830 sq ft)(4 ft)

= 11,300 cu ft

b. Rock volume = (0.065 ac)(4 ft)

= 0.26 ac ft

or Rock volume = (2830 sq ft)(4 ft) x $\frac{\text{ac}}{43560 \text{ sq ft}}$

= 0.26 ac ft

(11) Problem: Determine the (1) detention time, (2) overflow rate, (3) weir rate, for the rectangular clarifier of Problem 5, if the average daily flow is 600,000 gpd. Assume that the weir is located at the end of the tank with a length of 20 ft.

Solution: Detention time is the volume of the tank divided by the flow per unit time.

Therefore, Detention Time = $\frac{\text{Tank vol x 24 hr/day}}{\text{Daily flow}}$

Detention Time = $\frac{(60{,}000 \text{ gal}) \times 24 \text{ hr}}{600{,}000 \text{ gal/day day}}$ = 2.4 hr

Overflow rate is equal to the average daily flow divided by the surface area.

Therefore, Overflow rate = $\frac{\text{daily flow}}{\text{tank area}}$

$$\text{Overflow rate} = \frac{600{,}000 \text{ gal/day}}{800 \text{ sq ft}}$$

$$= \underline{\underline{750 \text{ gal/sq ft/day}}}$$

Weir rate is equal to the daily flow divided by the the total length of weir.

$$\text{Therefore, Weir rate} = \frac{\text{daily flow}}{\text{weir length}}$$

$$\text{Weir rate} = \frac{600{,}000 \text{ gal/day}}{20 \text{ ft}}$$

$$= \underline{\underline{30{,}000 \text{ gal/ft/day}}}$$

(12) Problem: Determine the (1) detention time, (2) overflow rate and (3) the weir rate for the circular clarifier of Problem 7, if the average daily flow is 600,000 gpd.

Solution: Tank volume = 47250 gal.

a. Detention time $= \dfrac{(47250 \text{ gal}) \times 24 \text{ hr/day}}{600{,}000 \text{ gal/day}} = \underline{\underline{1.9 \text{ hr}}}$

b. Overflow rate $= \dfrac{600{,}000 \text{ gal/day}}{1260 \text{ sq ft}}$

$$= \underline{\underline{475 \text{ gal/sq ft/day}}}$$

c. For all practical purposes, the weir length in a circular clarifier is equal to the circumference of the clarifier.

Therefore, for a 40-ft diameter clarifer,

Weir length = $\pi d = (\pi)(40 \text{ ft}) = 126$ ft

$$\text{Weir rate} = \frac{600{,}000 \text{ gal/day}}{126 \text{ ft}}$$

$$\text{Weir rate} = \underline{\underline{4750 \text{ gal/ft/day}}}$$

(13) Problem: Raw sewage entering a plant contains 200 ppm suspended solids. The average daily flow is 800,000 gpd. Determine the pounds of suspended solids per day entering the plant.

Solution: By definition there are 200 lb of suspended solids per 1,000,000 lb of raw sewage.

1 gal = 8.34 lb

Therefore, (8.34 lb/gal) (800,000 gal/day) =

6,700,000 lb sewage/day

$$\text{lb suspended solids} = 200 \text{ lb solids} \times \frac{6{,}700{,}000 \text{ lb}}{1{,}000{,}000 \text{ lb}}$$

sewage per day
sewage = $\underline{\underline{1340 \text{ lb}}}$

More conveniently, we could say:

(ppm)(mgd)(8.34) = pounds

(200)(0.8)(8.34) = $\underline{\underline{1{,}340 \text{ lb}}}$

(14) Problem: Over a period of time, we find that an average of 100 lb of chlorine is used per day for disinfection of the final effluent. The daily flow averages 1 mgd. Calculate the concentration of chlorine used in ppm.

Solution:
$$\text{ppm chlorine} = \frac{\text{lb chlorine}}{1{,}000{,}000 \text{ lb of effluent}}$$

$$= \frac{100 \text{ lb}}{(1 \text{ mgd})(8.34 \text{ lb/gal})} = \underline{\underline{12 \text{ ppm}}}$$

(15) Problem: Average suspended solids concentration in sewage entering a plant is 200 ppm. After treatment, the suspended solids in the final effluent average 20 ppm. Calculate the percent suspended solids removal accomplished in the treatment process.

Solution:
$$\% \text{ s.s. removal} = \frac{\text{suspended solids in} - \text{sus. solids out} \times 100}{\text{suspended solids in}}$$

$$= \frac{200 \text{ ppm} - 20 \text{ ppm}}{200 \text{ ppm}} \times 100$$

$$= \frac{180 \text{ ppm}}{200 \text{ ppm}} \times 100 = \underline{90\%}$$

(16) Problem: The average BOD of a plant influent is 180 ppm. After treatment, the BOD averages 35 ppm. Calculate the percent of BOD removed.

Solution:
$$\% \text{ BOD removed} = \frac{\text{BOD in} - \text{BOD out}}{\text{BOD in}} \times 100$$

$$= \frac{180 \text{ ppm} - 35 \text{ ppm}}{180 \text{ ppm}} \times 100$$

$$= \frac{145 \text{ ppm}}{180 \text{ ppm}} \times 100 = \underline{\underline{80.5 \%}}$$

(17) Velocity is the distance traveled in given time, or distance divided by time, such as miles per hour (MPH). Our work will commonly deal with velocity in feet per second (ft/sec). Let us convert 30 miles per hour to feet per second.

$$\frac{30\text{ miles}}{\text{hour}} \times 5280\,\frac{\text{feet}}{\text{mile}} \times \frac{\text{hr}}{60\text{ min}} \times \frac{\text{min}}{60\text{ sec}}$$

Canceling units, we have ft/sec

Computing, we have 44 ft/sec

Rate of flow is the volume passing a given point in a unit of time, or volume divided by time, such as cubic feet per second (cfs), gallons per minute (gpm), million gallons per day (mgd), etc.

$$500\,\frac{\text{gal}}{\text{min}} \times \frac{\text{cu ft}}{7.48\text{ gal}} \times \frac{\text{min}}{60\text{ sec}} = \underline{\underline{0.112\text{ cfs}}}$$

The standard flow formula is Q = AV where:

Q = rate of flow in cfs

A = cross-sectional area perpendicular to the direction of flow in sq ft.

V = velocity of flow in ft/sec.

It can be readily seen that, knowing the value of two of these units, the value of the third unit can easily be calculated by this formula.

(18) Problem: Determine the rate of flow in a 12-inch pipe flowing full if the velocity is 4 fps.

Solution: $Q = AV$

$$A = \pi r^2 = \frac{(\pi)(6\text{ in})(6\text{ in})}{144\text{ sq in/sq ft}} = 0.786\text{ sq ft}$$

$$Q = (0.786\text{ sq ft})(4\text{ ft/sec})$$

$$= \underline{\underline{3.14\text{ cfs}}}$$

(19) Problem: A piston pump set at a rating of 75 gpm is pumping sludge through a 6-inch line. How fast is the sludge traveling through the line?

Solution: $Q = AV \text{ or } V = \frac{Q}{A}$

1 cfs = 448 gpm

$$\text{Therefore, } Q = \frac{75\text{ gpm}}{448\text{ gpm/cfs}} = 0.168\text{ cfs}$$

$$A = \pi r^2 = \frac{(\pi)(3)\ in)(3\ in)}{144\ sq\ in/sq\ ft} = \frac{28.3\ sq\ in}{144\ sq\ in/sq\ ft}$$

$$= 0.196\ sq\ ft$$

$$V = \frac{Q}{A} = \frac{(0.168\ cu\ ft/sec)}{0.196\ sq\ ft} = \underline{\underline{0.86\ ft/sec}}$$

(20) Problem: Determine the velocity of flow in a rectangular grit channel 4 feet wide if the depth of flow in the channel is 1 foot and the flow is 2.5 mgd.

Solution: $Q = AV$ or $V = \frac{Q}{A}$

1 mgd = 1.547 cfs

Therefore, Q = (2.5 mgd)(1.547 cfs/mgd)

Q = 3.87 cfs

A = l x w = (4 ft)(1 ft) = 4 sq ft

$$V = \frac{Q}{A} = \frac{3.87\ cu\ ft/sec}{4\ sq\ ft} = \underline{\underline{0.97\ ft/sec}}$$

(21) Problem: In starting a digester, you are filling it with raw sewage. If the digester capacity is 6000 cu ft and sewage is being pumped into it at a rate of 100 gpm, how many hours will be required to fill the tank?

Solution: 1 cu ft = 7.5 gal

Therefore, $\frac{100\ gal}{min} \times \frac{cu\ ft}{7.5\ gal} = 13.4\ cu\ ft/min$

In other words, 13.4 cu ft of sewage will be pumped to the digester every minute. Therefore, to fill the digester, it would require:

$$\frac{6{,}000\ cu\ ft}{(13.4\ cu\ ft/min)(60\ min/hr)} = \underline{\underline{7.48\ hr}}$$

(22) Temperature measurements in both degrees Centigrade and in degrees Fahrenheit are common in treatment plant work. It is often necessary to convert from one temperature to the other. The conversion formulas are as follows:

$^oC = 5/9\ (^oF - 32)$

$^oF = 9/5\ (^oC) + 32$

Where: ^oC = degrees Centigrade

^oF = degrees Fahrenheit

(23) Problem: Convert 75° F to degrees Centigrade

Solution: $^{o}C = 5/9\ (^{o}F - 32)$

$= 5/9\ (75 - 32)$

$= 5/9\ (43)$

$^{o}C = \underline{\underline{23.9}}$

(24) Problem: Convert 20° C to degrees Fahrenheit

Solution: $^{o}F = 9/5\ (^{o}C) + 32$

$= \frac{(9)(20)}{5} + 32$

$= 36 + 32$

$^{o}F = \underline{\underline{68}}$

The average is the sum of the items divided by the number of items.

(25) Problem: If the daily sewage flows are 3.3 mg, 4.6 mg, and 4.0 mg, what is the average daily flow?

Solution: Average daily flow =

$$\frac{3.3\text{ mg} + 4.6\text{ mg} + 4.0\text{ mg}}{3} = \frac{11.9\text{ mg}}{3} = \underline{\underline{3.97\text{ mg}}}$$

(26) Problem: An operator runs a weekly suspended solids test on a sample of raw sewage. Over a month's period he finds the suspended solids concentrations to be 200 ppm, 180 ppm, 240 ppm, and 160 ppm. What is the average suspended solids concentration for the month?

Solution: Average concentration =

$$\frac{200\text{ ppm} + 180\text{ ppm} + 240\text{ ppm} + 160\text{ ppm}}{4} = \frac{780\text{ ppm}}{4} =$$

$\underline{\underline{195\text{ ppm}}}$

(27) Problem: If 3.75 lb of H.T.H. containing 70 percent available chlorine is dissolved in 30 gallons of water, what is the percent (%) available chlorine in the solution?

3.75×0.70 = lbs available chlorine
= 0.263 lbs
$\frac{3.75 \times 0.70}{30 \times 84} = \frac{0.263}{250}$ = lbs available chlorine in 1 lb of solution
= .0105
100×0.0105 = 1.05%

In dilute solutions, the weight of water may be taken as equal to the weight of the solution.

(28) Problem: Suspended solids in the influent is 600 ppm and in the effluent 400 ppm. What is the percent efficiency of removal?

$600 - 400$ = 200 removed
$\frac{200}{600}$ = 0.333

0.333×100 = 33.3%

PHYSICAL LAWS

Physical laws have to do with forces, weights, motion, control of motion, electricity and heat. In most instances the laws of forces, motion, heat and electricity work together in fairly prescribed patterns. However, the calculations involved in working with the combined group are very difficult. Therefore, it is customary to assume that certain items are held constant. In this way there are enough known values to solve the resulting equations.

1. **Fundamental Concepts and Definitions.**

A. Length. Length is a fundamental unit (the distance between two points). The metric standard is the meter, 100 centimeters (39.37 inches) and the English standard is the yard. One inch is equavalent to 2.54 centimeters.

B. Time. Time is a fundamental unit. It is expressed in seconds, minutes, hours, days and years. The unit most commonly used is the second which is $\frac{1}{86,400}$ of a mean solar day.

C. Mass. Mass is a measure of inertia (property of matter such that resistance is offered to change in motion).

D. Force. Force is a push or pull which tends to produce change of motion. Weight which is the pull of gravity is a typical force. Units are in the pound system or the kilogram system.

E. Combinations of these units give the physical relationships that are familiar to most people in one form or another.

(1) Speed or velocity is expressed in terms of length or distance per unit of time. The units of ft/sec and miles /hour (MPH) are common examples.

(2) Flow or capacity is expressed in terms of volume per unit of time. Common units are gallons per minute (GPM) and cubic feet per second (cfs or ft^3 /sec).

(3) Work is defined as a force acting through a distance. Its units are foot-pounds (ft-lb) in the English system and ergs (dyne-cm) in the metric system.

(4) Power is the time-rate at which work is done. Units are ft-lb/sec. One horsepower is 550 ft-lb/sec.

(5) Energy is the capacity to do work and is acquired by a body as a result of having work done on it. It is potential energy if it is dependent on position or shape. It is kinetic energy if it is dependent on motion.

(6) Heat is a form of energy and is expressed in British Thermal Units (Btu) or calories. There are 778 ft-lb per Btu. Temperature is a measure of heat. Probably the most important concept is that heat flows from high to low temperature regions.

(7) Electricity as used herein is energy in the form of flow of electrons.

(8) Light travels through space in straight lines at 186,000 miles per second.

(9) Sound is a wave action which varies depending on the type of media that is carrying it. At 0 degrees Centigrade the velocity in air is 1,090 ft/sec. The velocity increases 2 ft/sec for every zero-degree Centigrade rise in temperature.

2. **Application of Fundamentals.**

A. Forces are defined by both size and direction of action. For example weight acts downward (toward the center of the earth). Any other force must be defined by its magnitude and its direction as shown by angle or some other reference to a known direction. The principal is illustrated below:

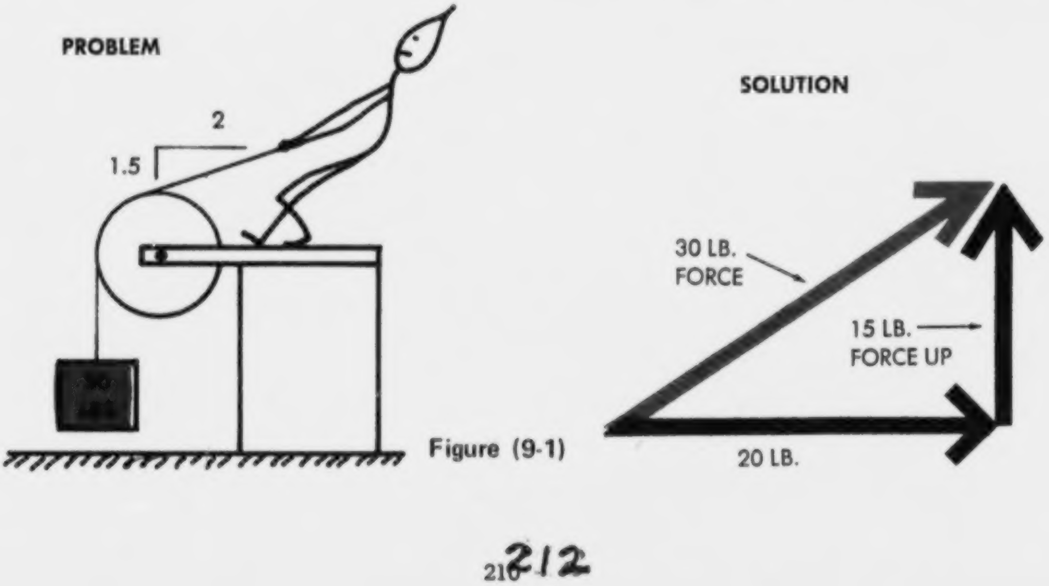


Figure (9-1)

To every force there is an equal and opposite force if the system is in static equilibrium, that is, if the system is not moving. This system can be illustrated by a balance teeter-totter.

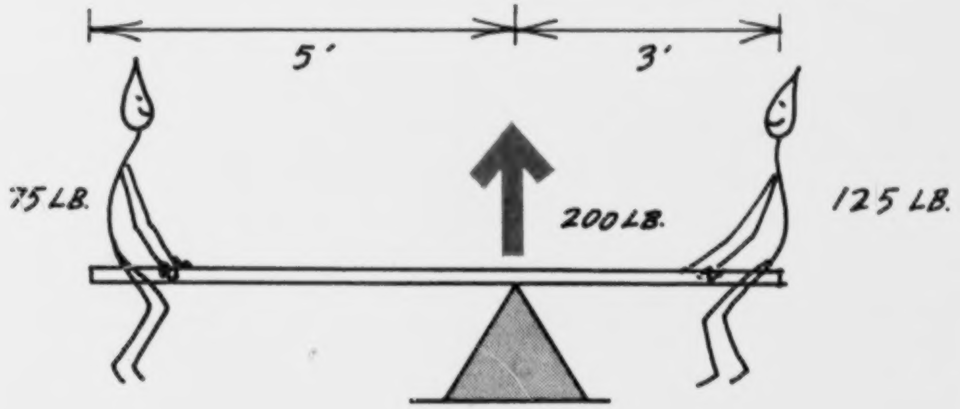
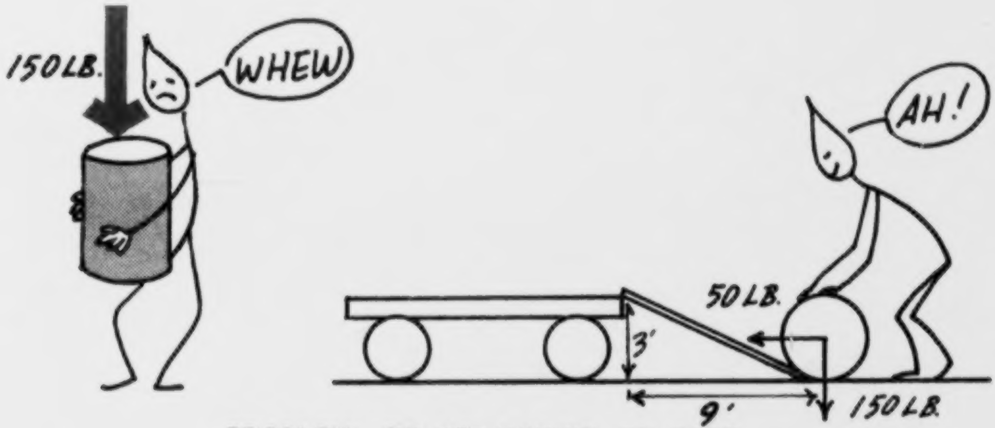

5'
3'
75 LB.
200 LB.
125 LB.

Figure (9-2)

An inclined plane is another illustration of the use of forces for making a job easier.


150 LB.
WHEW
AH!
50 LB.
3'
9'
150 LB.

PROBLEM: TO GET BARREL ON CART
Figure (9-3)

Friction force is used both for and against the operator. Lubrication on shafts and moving parts is done to cut down the friction values. Friction depends on weight of the load and the materials in contact. To illustrate, assume a 200-pound concrete block on concrete. The reverse force is 0.6 of the 200-pound load.

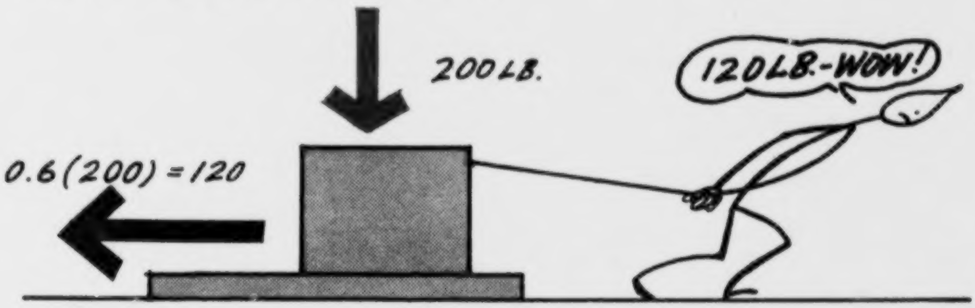
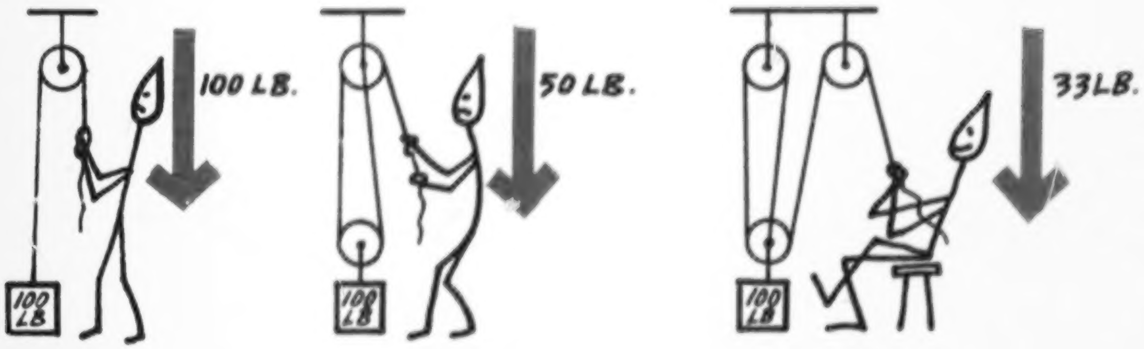

200 LB.
120 LB.-WOW!
0.6(200) = 120

Figure (9-4)

Pulley systems and block and tackle arrangements are examples of multiplication of forces.



Single Pulley **Double Pulley** **Multiple Pulley**

Figure 9-5

B. Work combines force and distance. When any weight is moved through a distance work is done.

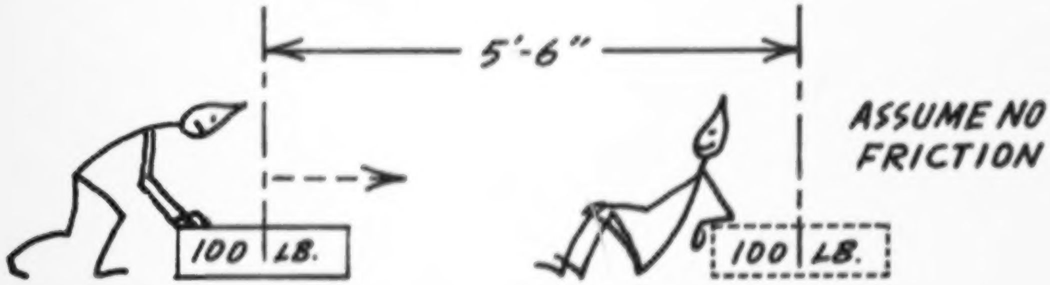

5'-6"
ASSUME NO FRICTION
100 LB.
100 LB.

Figure 9-6

$$\begin{aligned} \text{Work} &= \text{Force times distance} \\ &= F \times d \\ &= 100 \text{ lb} \times 5.5 \text{ ft} \\ &= 550 \text{ ft-lb} \end{aligned}$$

C. Power has the added unit of time. For example in the illustration above, if the little man shoved the 100-pound block to its new location in one second the power he used would be:

$$\text{Power} = \frac{F \times d}{t} = \frac{100 \text{ lb} \times 5.5 \text{ ft}}{1 \text{ sec}} = \frac{550 \text{ ft-lb}}{\text{sec}}$$

which is equivalent to 1 horsepower of work.

D. Speed or velocity is defined as a distance per unit of time. If an automobile is driven 301 miles in 7 hours its average speed is:

$$\text{Speed} = \frac{\text{total miles}}{\text{hours}}$$

Another factor associated with speed is a term called acceleration which is change in speed per unit time. It can best be illustrated by the following diagram:

$$V = \frac{d}{t} = \frac{301}{7} = 43 \text{ miles/hr}$$

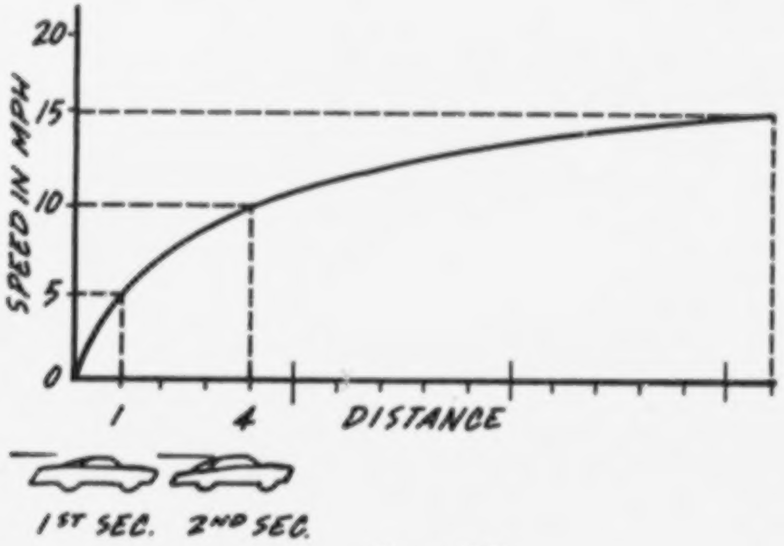
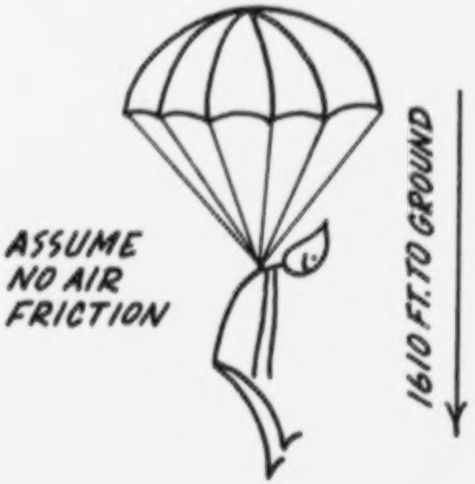


Figure (9-7)

At the end of the first second the velocity is 5 mph; at the end of the second second the velocity is 10 mph; and at the end of the third second it is 15 mph. The velocity has increased by 5 mph each second and therefore the car has a uniform acceleration of 5 mph/sec.

Similar reasoning can be used for illustrating the gravity constant g, which is 32.2 ft/sec per sec. Say 1610 ft fall.

Figure (9-8)



$$\text{distance} = 1/2\ gt^2$$

$$\text{or time} = \sqrt{\frac{\text{distance}}{1/2\ g}}$$

$$t = \sqrt{\frac{1610}{16.1}} = 100 = 10 \text{ sec}$$

E. Flow or capacity is used mostly in fluid measurements, but are illustrated here because the units include velocity per unit of time. Look at a section of a pipe line with water flowing through it.

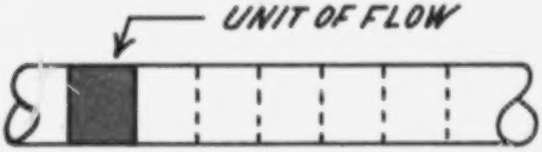


Figure (9-9)

If the unit of flow is one cubic foot and it moves along the pipe line with a movement of 1 unit per second the quantity of flow is:

Q = Unit of flow per second

but it is not always possible to have one unit moving at 1 unit per second, so it is necessary to break the units down further. It can be seen that $Q = \frac{\text{cubic feet}}{\text{sec}}$ and two measurable items are observable in these units, the area of the pipe in ft^2 and the velocity of the flow in ft/sec. Combining these, the general equation becomes:

Quantity of flow = Area of cross section times average velocity or Q = AV

In a pipe line of 6-inch diameter with a velocity of 5 feet per second.

$$Q = \frac{\pi}{4}(1/2)^2(5) = \frac{\pi}{4}(1/4)(5) = 0.982\ ft^3/sec$$

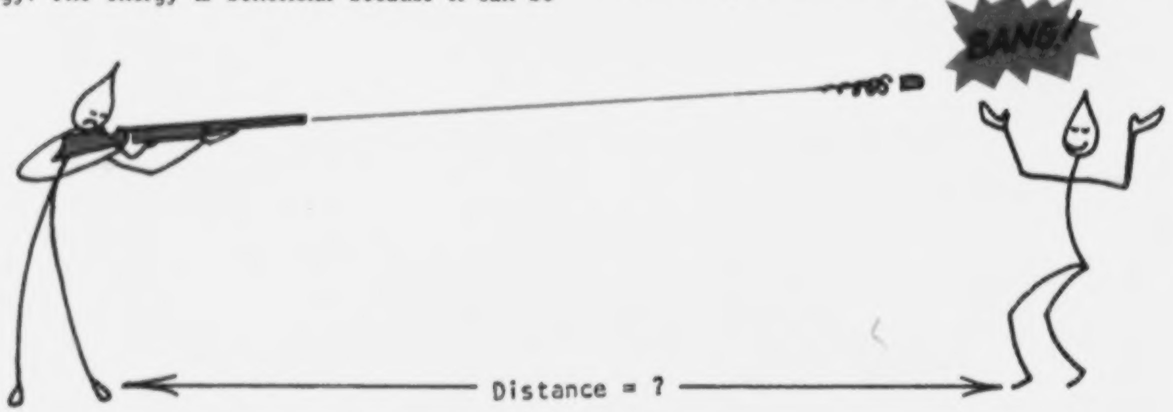
3. **Heat, Sound, Light, and Electricity.**

A. Heat can stem from chemical energy, electrical energy, mechanical energy or radiant energy. The energy is beneficial because it can be transformed into useful work. It can also be a detriment if it is uncontrolled. In a short summary such as this it is not possible to cover the subject of heat. All that can be done is to note that the energy of heat is contained in sewage and other wastes and becomes available for use. For example the gas that is given off from a digester is used in a furnace to provide heat for the plant and for the digester so that it will provide a larger volume of gas. Heat is absorbed, reflected, transmitted and radiated by various materials. The resistance of an electrical circuit can provide heat. The conductance of metallic surfaces is used to lead off heat into the atmosphere for dissipation. It is a well known fact that rough, dark surfaces absorb heat and that smooth, bright surfaces reflect heat. Expansion and contraction of gases, liquids and solids are functions of the heat condition of the materials.

B. Sound is an interesting effect which people experience because the ear is tuned to receive vibrations of various wave lengths. Each sound has a specific wave length. The cycles of the wave length occur in a time sequence that is called frequency. The velocity of a sound is determined by the frequency times the wave length.

Velocity (V) = frequency (f) x wave length (1)

The velocity also depends on the nature of the material through which the sounds pass and on the temperature of the media. It is least in gases and greatest in solids, for example, about 15 times as fast in steel as in air. It varies about 2 ft/sec for each zero-degree Centigrade change in temperature. At zero degrees Centigrade in air the velocity averages 1090 ft/sec. An example problem envisions a gun flash and hearing the report 9.2 seconds afterward. Temperature is 15 degrees Centigrade.


BANG!
Distance = ?

Time = 9.2 seconds

Velocity of sound = 1090 + (2 x 15) = 1120 ft/sec

Distance = vt = 1120 x 9.2 = 10,300 ft

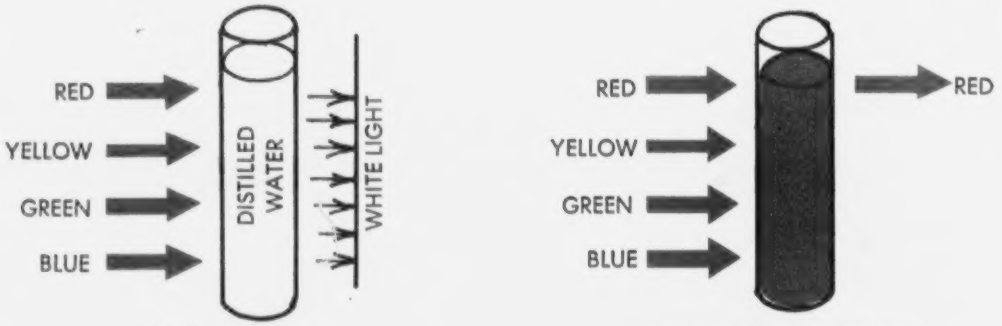
Figure (9-10)

C. Light is a very useful phenomenon which is a daily item that we tend to take for granted. The sun provides the major source of light, and it reaches the earth at a speed of about 186,000 miles per second. Other sources are hot bodies, chemical reactions, electrical disturbances in a gas and phosphorescence. Intensity of illumination is a measure of the amount of light falling on a unit area. The equation for this intensity is:

$$\text{Intensity of illumination} = \frac{\text{candle power of source}}{\text{square of distance from source}}$$

Nearly everyone now uses this generalized equation in photography. The light meter is a measure of the intensity of illumination.

The white light that we see contains within it colors such as we see when the light is refracted to form a rainbow. Use is made of this characteristic of light in colorimetric determinations of chemical changes that have color end points. The following diagrams illustrate the fundamentals of colorimetric work.



PASSES ALL
VISIBLE WAVELENGTHS

RED LIQUID ABSORBS ALL
WAVELENGTHS EXCEPT RED

Figure 9-11

The colorimeter uses a filter in the path of light to make measurements as shown below:

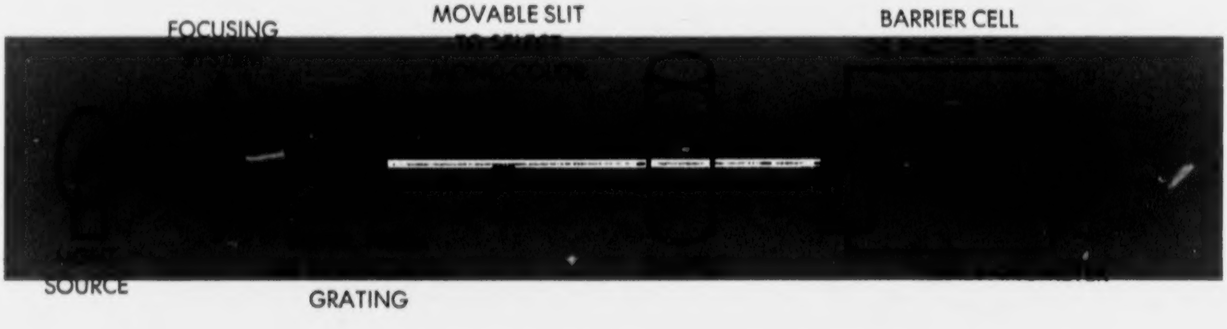
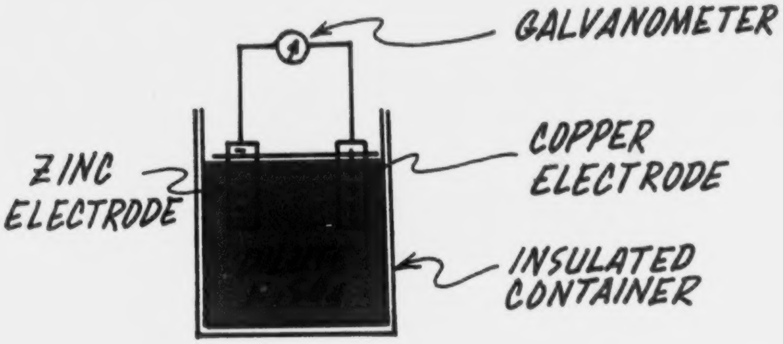
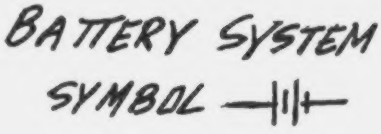


Figure 9-12

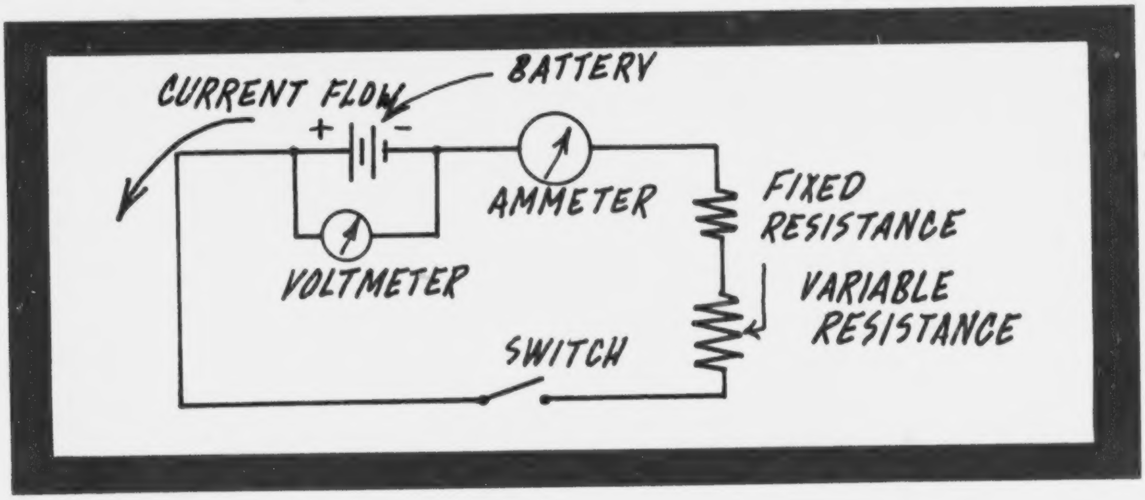
D. Electricity is the flow of electrons from a point of high potential or power stems from a battery or generating system. There are two forms of electricity with which we are generally concerned, direct and alternating current. The direct current is a steady flow of electrons in the same direction. An alternating current, on the other hand, continuously changes in magnitude and reverses direction periodically. Transmission of electricity involves use of conducting lines and insulators to keep lines apart.

Every electrical circuit must contain a source of potential in "volts," flow of current in "amperes," and resistance to flow in "ohms." A battery source is used for direct current. It is a system made up of materials which act as electrodes that give an electric current when placed in a solution called an electrolyte.


GALVANOMETER
COPPER ELECTRODE
ZINC ELECTRODE
INSULATED CONTAINER


BATTERY SYSTEM
SYMBOL

Now look at a circuit built up of the component parts.


CURRENT FLOW
BATTERY
+
-
AMMETER
FIXED RESISTANCE
VARIABLE RESISTANCE
VOLTMETER
SWITCH

These circuits can be solved for unknowns by Ohm's Law which states that voltage equals current times resistance, so that

$E = IR$ where E = voltage
I = current in amperes
R = resistance in Ohms

The equation may also be written

$$I = \frac{E}{R} \text{ or } R = \frac{E}{I}$$

Example: An electric toaster operating on 120 volts draws a current of 6 amperes. The resistance of the coil is:

$$R = \frac{E}{I} = \frac{120}{6} = 20 \text{ ohms}$$

Power in electrical circuits is the rate of doing work. The unit of electrical power is the Watt. One watt is the power developed when one ampere flow under a pressure of one volt. Written in mathematical symbols $W = E1$. Generally the power is measured in kilowatt (1000 watt) units. This can be related to mechanical power through the conversion relationship.

1 killowatt = 1-1/3 horsepower or

1 horsepower = 0.746 kilowatts (KW).

[redacted]

Say voltage is 220 furnished to a 10 hp motor and pump which has an overall efficiency of 90%. What is the current in the lines?

$$\text{Power to motor} = \frac{10 \text{ hp}}{0.9} \times \frac{0.746 \text{ kw}}{\text{HP}} = 8.3 \text{ kw}$$

$$\text{Current} = \frac{W}{E} = \frac{8{,}300 \text{ watts}}{220 \text{ volts}} = 37.7 \text{ amperes}$$

If power costs one cent per kilowatt-hour and the pump was operated 10 hours per day for 25 days each month, what is the cost of power?

$$\text{Total power used} = 8.3 \text{ kw } (250 \text{ hrs}) = 1835 \text{ kw-hr}$$

$$\text{Cost} = 1835 \text{ kw-hr} \times \frac{\$0.01}{\text{kw-hr}}$$

$$= \$18.35$$

HYDROLOGY AND HYDRAULICS

1. **Hydrology.** The subject of hydrology deals with the study of water, that is, what it is, where it occurs and how it is distributed. It deals mainly with precipitation and the amount of water that either runs off from the earth or is absorbed by it. Hydrology also has to do with evaporation from the earth and transpiration from plants. Water is picked up from the ocean by the energy of the sun and forms clouds which travel across the country and eventually drop their loads of water as rain, snow, sleet, or hail. When it reaches the ground it starts its torturous path back to the ocean, picking up all sorts of material as it flows. In the sewage works field operators must consider the effect of sewage effluents on the waters because these waters flow past others and are used for many beneficial uses.

In the west, prevailing westerly winds pick up moisture from the Pacific Ocean. Two parallel mountain ranges, the Coast Range, and the aptly-named Cascades cool the moisture-laden air, and it is pretty well wrung out by the time it reaches the central plains on the east side of the Cascades. Schematically the pattern is as follows:

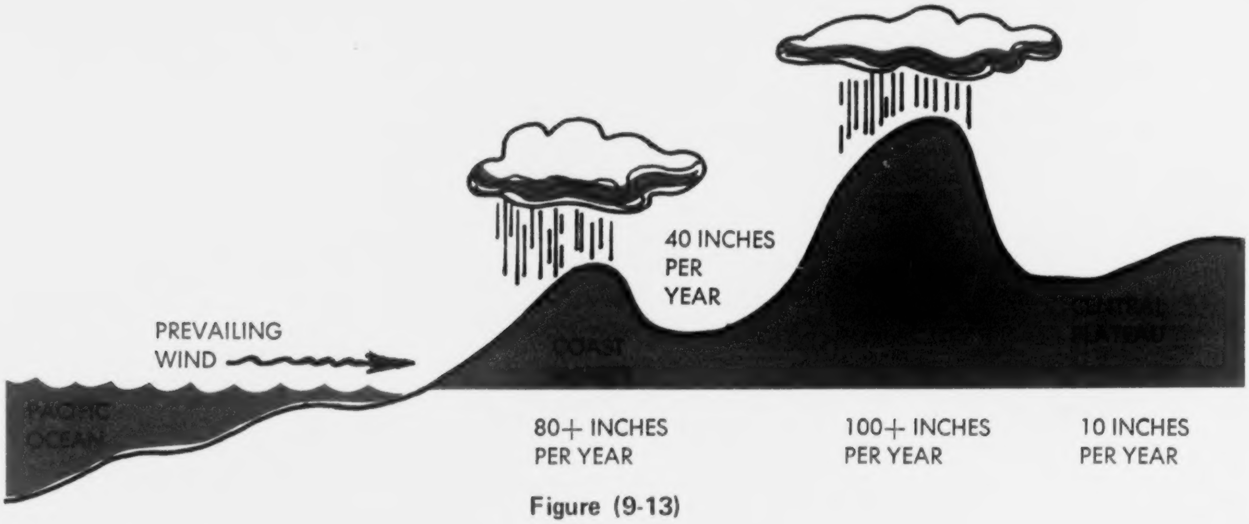


Figure (9-13)

Most of the heavy rainfall runs back to the coast or down the valley and plateau streams to the Columbia during the winter months and does little useful work. It does, however, flood sewers and plants to cause many difficulties to operations.

The Weather Bureau is reasonably proficient in using back records and present circumstances to keep people up-to-date on weather. The U. S. Geological Survey does an excellent job of measuring surface stream flows and groundwater conditions at stations where they can get matching money assistance. The USGS publishes water supply papers which show annual average flows, daily flows, maximum flows and minimum flows that pass specified points. Because USGS does lack funds they cannot measure all streams, and it is often necessary for other agencies to make measurements. This is a relatively simple procedure.

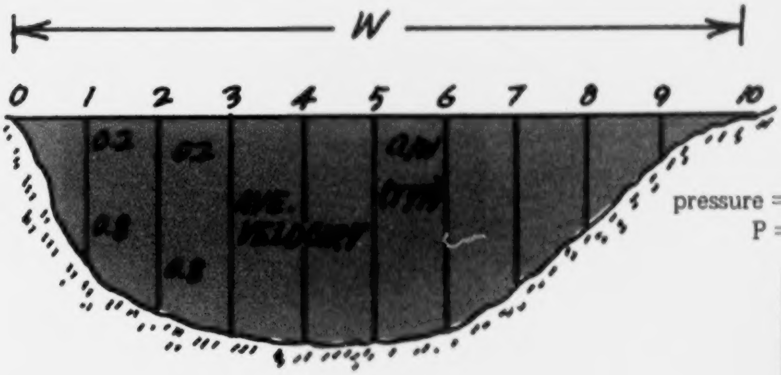
A. Stream Flow Measurement.

(1) divide the stream width into even increments of width.

(2) measure velocity with current meter at 0.2 depth and 0.8 depth.

(3) average the velocities on each side of the section.

(4) find area of section $\frac{(d_1 + d_2)}{2}(0.1W)$



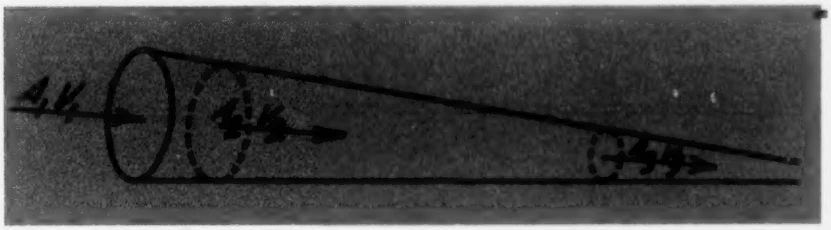
(5) find Q in section by multiplying Area times Velocity.

(6) add all Q values for total flow in the stream.

This must be carefully done to obtain an accuracy of about 10 percent.

2. **Hydraulics.** Hydraulics constitutes the major problem in sewage works. Water flows from place to place either because it has potential energy due to its height above a point or it has kinetic energy due to its motion.

A. The law of Continuity. Quantity of flow equals area of cross-section times velocity of flow in any closed system is one in main use in the field. Pictorially the law may be shown as follows:

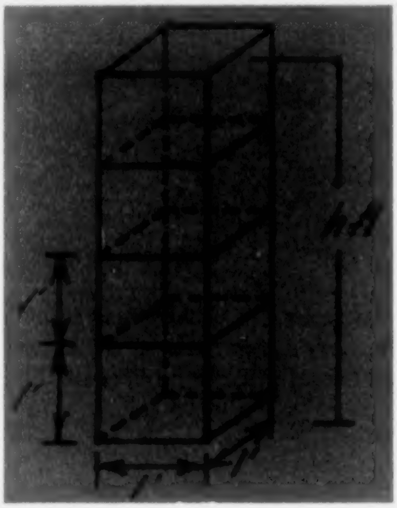


$$Q = A_1V_1 = A_2V_2 = A_3V_3$$

B. Pressure. Pressure is the hydraulic force that water exerts due to its weight. Assume a cubic foot box full of water. The water exerts a 62.5-pound force on a 1 square foot area. If another box is joined, the pressure becomes 62.5(2). If h feet are added then the general equation becomes:

pressure = weight per unit volume times height

$P = Wh$



p = 62.5 psf per foot of height of water

= 1 psi for 2.31 feet of water

No matter how wide the holding basin may be, the unit pressure will remain proportional to height only. Total force, however, does vary with the base on which the pressure acts and F = pA.

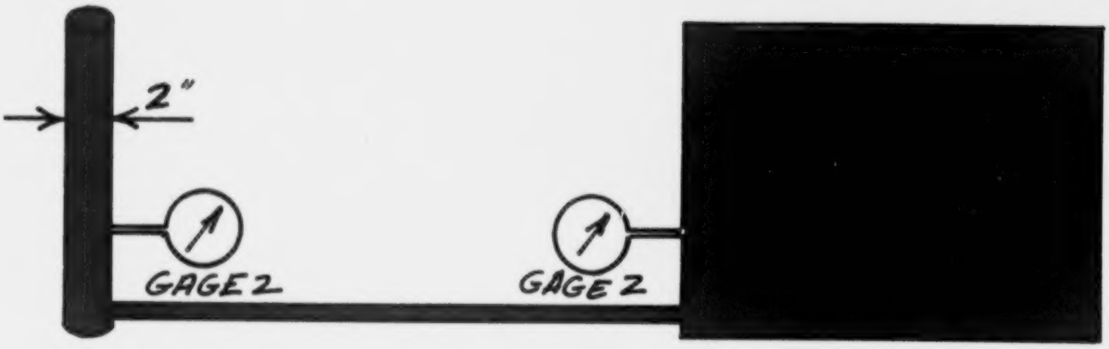


Figure (9-14)

Pressures are usually read in pounds per square inch (psi) rather than psf. What we read on a gauge is not absolute pressure because the atmosphere exerts a pressure of 14.7 psi at sea level.

Forces may be transmitted through hydraulic fluid by use of the pressure concept.

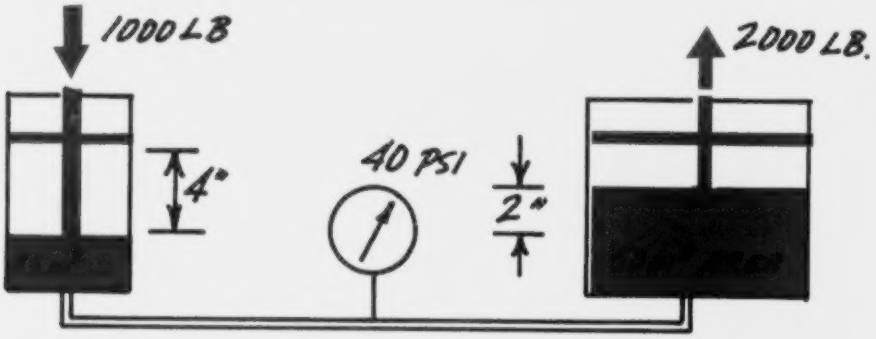


Figure (9-15)

C. Energy Equation (Bernoulli Equation). The following diagrams show the types of energy involved in pipe line flow and a method for solving for unknown factors.

Mechanical Equivalent of Hydraulic Lever

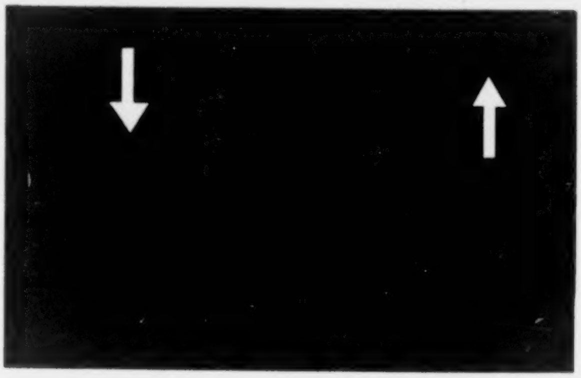


Figure (9-16)

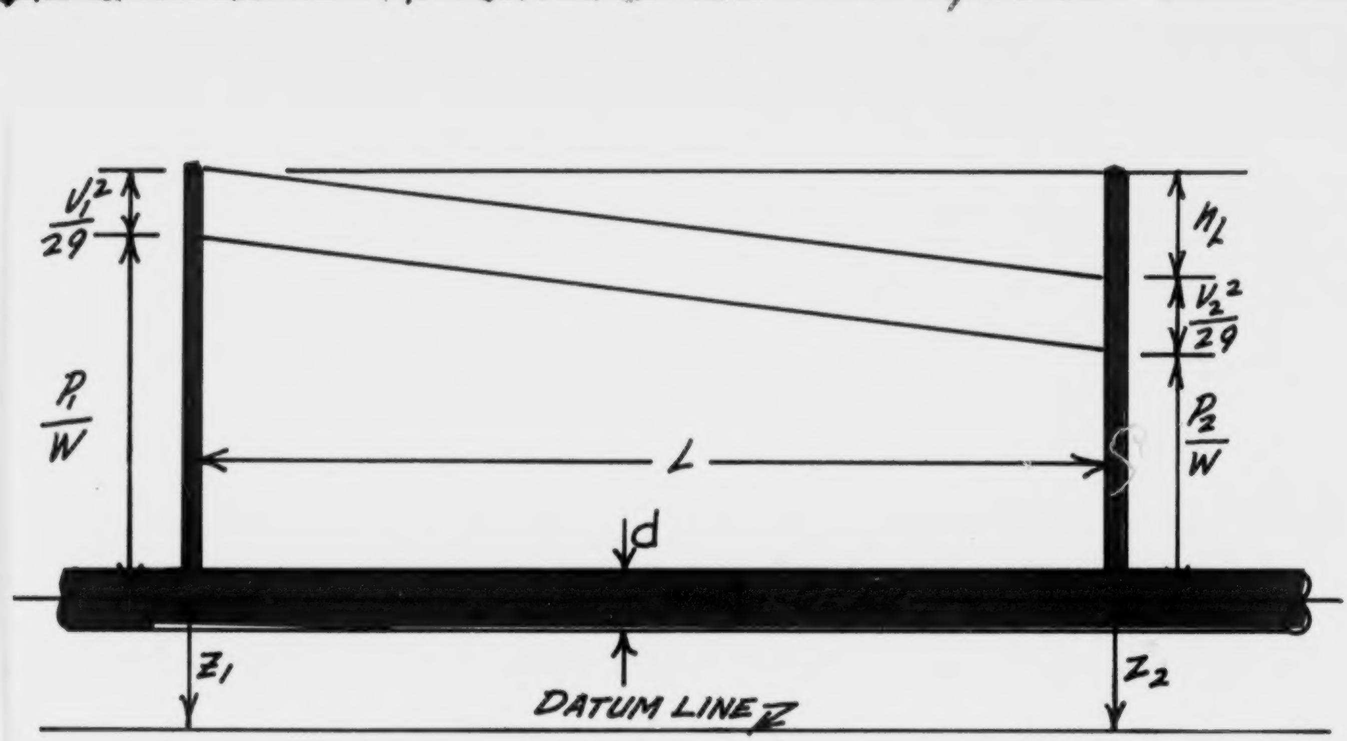


Figure (9-17)

Z_1 and Z_2 are elevations above a known line like a floor.

$\frac{V^2}{2g}$ stems from Toricelli's equation $V = \sqrt{2gh}$ = velocity head

$\frac{P}{W}$ stems from the equation $p = Wh$

h_L is the head loss due to pipe friction and equals

$\frac{flv^2}{d\ 2g}$ where f = friction factor $= \frac{20}{1000}$ for approximation

L = length of pipe

d = diameter of pipe

$\text{Energy}_1 = \text{Energy}_2 + \text{losses}$

$$Z_1 + \frac{P_1}{W} + \frac{V_1^2}{2g} = Z_2 + \frac{P_2}{W} + \frac{V_2}{2g} + h_L$$

The usefulness of this equation can be demonstrated by using the tools available to operators. If the Z values are measured and gauges are put in to measure $\frac{P}{W}$ the remaining variable is velocity which stays constant throughout the pipe so that $V_1 = V_2$. This long procedure is seldom followed in practice because manufacturers have used equations to compute tables so that factors can be picked directly without computations. For example if a level 4-inch diameter pipe line 500 feet long showed a change of pressure of 10 psi we can find the approximate flow from Table 9-7. Ten psi = 23.1 ft of head loss or 23.1/5 = 4.6 ft/100 ft. Reading down the 4-inch pipe column to 4.4 ft/100 ft, it can be seen that 200 gpm would be flowing in the pipe at 5.1 ft/sec velocity.

When water is pumped from a lower elevation to a higher one energy is required. The horsepower represented on a theoretical basis is

$$\text{H.P.} = \frac{\text{Q (qpm)} \times \text{H (ft.)}}{3960 \times \text{Efficiency}}$$

Table 9-8 is set up to solve this above equation. For example if it is desired to pump 150 gpm at 100 ft of head, the theoretical horsepower is 3.75. In general, however, there is loss in efficiency through the pump and motor so that a larger power source is needed. If the sytem is 80 percent efficient the needed HP = $\frac{3.77}{.8}$ = 4.7 so a 5 HP motor would probably be used.

D. Open Channel Flow. Open channel flow is the usual type in sewage treatment. The necessary equation for solving problems is the old familiar Q = AV. Areas are usually relatively easy to measure and velocity becomes the problem. The basic equation is the "Chezy" equation:

$V = C\sqrt{rS}$ where r = hydraulic radius

$= \frac{\text{area}}{\text{welted perimeter}}$

$S = \text{slope} = \frac{Ah}{L}$

C = Chezy coefficient

Manning has defined the C value as $\frac{1.486\ r^{1/6}}{n}$ so that

$$Q = \frac{1.486}{n}\ A\ r^{2/3}\ S^{1/2}$$

n = roughness factor

Example: A 24-inch diameter pipe is flowing half full. It has a slope of 2 ft per 1000 ft. What is the flow?

n = 0.013.

$$A = (1/2)\ (\pi)\ (r^2) = (1/2)(3.14)(1) = 1.57\ \text{ft}^2$$

$$\text{Welted perimeter} = (1/2)\ (2\pi)\ (r) = 3.14\ \text{ft}$$

$$R = \frac{1.57}{3.14} = 0.5$$

$$Q = \frac{1.486}{0.013}\ (1.57)(0.5)^{2/3}(0.020)^{1/2} = 0.75\ \text{cfs}$$

Weirs are another type of measuring system. The weir must be sharp-edged so that a critical depth occurs over the weir. Measurement of head is made upstream from the weir as shown below.

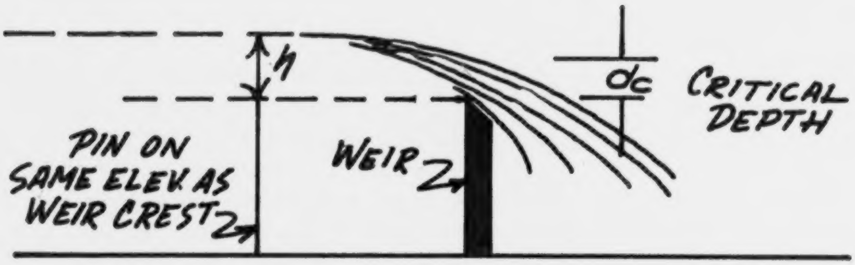


Figure (9-18)

TABLE 9-7

FRICTION LOSS OF WATER IN FEET PER 100 FEET LENGTH OF PIPE. BASED ON WILLIAMS & HAZEN FORMULA USING CONSTANT 100. SIZES OF STANDARD PIPE IN INCHES

U.S. Gals. Per min	½" Pipe		3/4" Pipe		1" Pipe		1¼" Pipe		1½" Pipe		2" Pipe		2½" Pipe		3" Pipe		4" Pipe		5" Pipe		6" Pipe		U.S. Gals. Per min.
	Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	Vel. 'per Sec.	Loss in Feet	
2	2.10	7.4	1.20	1.9																			2
4	4.21	27.0	2.41	7.0	1.49	2.14	.86	.57	.63	.26													4
6	6.31	57.0	3.61	14.7	2.23	4.55	1.29	1.20	.94	.56	.61	.20											6
8	8.42	98.0	4.81	25.0	2.98	7.8	1.72	2.03	1.26	.95	.82	.33	.52	.11									8
10	10.52	147.0	6.02	38.0	3.72	11.7	2.14	3.05	1.57	1.43	1.02	.50	.65	.17	.45	.07							10
12			7.22	53.0	4.46	16.4	2.57	4.3	1.89	2.01	1.23	.79	.78	.23	.54	.10							12
15			9.02	80.0	5.60	25.0	3.21	6.5	2.36	3.00	1.53	1.08	.98	.36	.68	.15							15
18			10.84	108.2	6.69	35.0	3.86	9.1	2.83	4.24	1.84	1.49	1.18	.50	.82	.21							18
20			12.03	136.0	7.44	42.0	4.29	11.1	3.15	5.20	2.04	1.82	1.31	.61	.91	.25	.51	.06					20
25					9.30	64.0	5.36	16.6	3.80	7.30	2.55	2.73	1.63	.92	1.13	.38	.64	.09					25
30					11.15	89.0	6.43	23.0	4.72	11.0	3.06	3.84	1.96	1.29	1.36	.54	.77	.13	.49	.04			30
35					13.02	119.0	7.51	31.2	5.51	14.7	3.57	5.10	2.29	1.72	1.59	.71	.89	.17	.57	.06			35
40					14.88	152.0	8.58	40.0	6.30	18.8	4.08	6.6	2.61	2.20	1.82	.91	1.02	.22	.65	.08			40
45							9.65	50.0	7.08	23.2	4.60	8.2	2.94	2.80	2.04	1.15	1.15	.28	.73	.09			45
50							10.72	60.0	7.87	28.4	5.11	9.9	3.27	3.32	2.27	1.38	1.28	.34	.82	.11	.57	.04	50
55							11.78	72.0	8.66	34.0	5.62	11.8	3.59	4.01	2.45	1.58	1.41	.41	.90	.14	.62	.05	55
60							12.87	85.0	9.44	39.6	6.13	13.9	3.92	4.65	2.72	1.92	1.53	.47	.98	.16	.68	.06	60
65							13.92	99.7	10.23	45.9	6.64	16.1	4.24	5.4	2.89	2.16	1.66	.53	1.06	.19	.74	.076	65
70							15.01	113.0	11.02	53.0	7.15	18.4	4.58	6.2	3.18	2.57	1.79	.63	1.14	.21	.79	.08	70
75							16.06	129.0	11.80	60.0	7.66	20.9	4.91	7.1	3.33	3.00	1.91	.73	1.22	.24	.85	.10	75
80							17.16	145.0	12.59	68.0	8.17	23.7	5.23	7.9	3.63	3.28	2.04	.81	1.31	.27	.91	.11	80
85							18.21	163.8	13.38	75.0	8.68	26.6	5.56	8.1	3.78	3.54	2.17	.91	1.39	.31	.96	.12	85
90							19.30	180.0	14.71	84.0	9.19	29.4	5.88	9.8	4.09	4.08	2.30	1.00	1.47	.34	1.02	.14	90
95									14.95	93.0	9.70	32.6	6.21	10.8	4.22	4.33	2.42	1.12	1.55	.38	1.08	.15	95
100	8" PIPE								15.74	102.0	10.21	35.8	6.54	12.0	4.54	4.96	2.55	1.22	1.63	.41	1.13	.17	100
110									17.31	122.0	11.23	42.9	7.18	14.5	5.00	6.0	2.81	1.46	1.79	.49	1.25	.21	110
120									18.89	143.0	12.25	50.0	7.84	16.8	5.45	7.0	3.06	1.17	1.96	.58	1.36	.24	120
130									20.46	166.0	13.28	58.0	8.48	18.7	5.91	8.1	3.31	1.97	2.12	.67	1.47	.27	130
140	.90	.08							22.04	190.0	14.30	67.0	9.15	22.3	6.35	9.2	3.57	2.28	2.29	.76	1.59	.32	140
150	.96	.09									15.32	76.0	9.81	25.5	6.82	10.5	3.82	2.62	2.45	.88	1.70	.36	150
160	1.02	.10									16.34	86.0	10.46	29.0	7.26	11.8	4.08	2.91	2.61	.98	1.82	.40	160
170	1.08	.11	10" PIPE								17.36	96.0	11.11	34.1	7.71	13.3	4.33	3.26	2.77	1.08	1.92	.45	170
180	1.15	.13									18.38	107.0	11.76	35.7	8.17	14.0	4.60	3.61	2.94	1.22	2.04	.50	180
190	1.21	.14									19.40	118.0	12.42	39.6	8.63	15.5	4.84	4.01	3.10	1.35	2.16	.55	190
200	1.28	.15									20.42	129.0	13.07	43.1	9.08	17.8	5.11	4.4	3.27	1.48	2.27	.62	200
220	1.40	.18	.90	.06							22.47	154.0	14.38	52.0	9.99	21.3	5.62	5.2	3.59	1.77	2.50	.73	220
240	1.53	.22	.98	.07							24.51	182.0	15.69	61.0	10.89	25.1	6.13	6.2	3.92	2.08	2.72	.87	240
260	1.66	.25	1.06	.08							26.55	211.0	16.99	70.0	11.80	29.1	6.64	7.2	4.25	2.41	2.95	1.00	260
280	1.79	.28	1.15	.09									18.30	81.0	12.71	33.4	7.15	8.2	4.58	2.77	3.18	1.14	280
300	1.91	.32	1.22	.11									19.61	92.0	13.62	38.0	7.66	9.3	4.90	3.14	3.40	1.32	300
320	2.05	.37	1.31	.12	12" PIPE								20.92	103.0	14.52	42.8	8.17	10.5	5.23	3.54	3.64	1.47	320
340	2.18	.41	1.39	.14									22.22	116.0	15.43	47.9	8.68	11.7	5.54	3.97	3.84	1.62	340
360	2.30	.45	1.47	.15			14" PIPE						23.53	128.0	16.34	53.0	9.19	13.1	5.87	4.41	4.08	1.83	360
380	2.43	.50	1.55	.17	1.08	.069							24.84	142.0	17.25	59.0	9.69	14.0	6.19	4.86	4.31	2.00	380
400	2.60	.54	1.63	.19	1.14	.075							26.14	156.0	18.16	65.0	10.21	16.0	6.54	5.4	4.55	2.20	400
450	2.92	.68	1.84	.23	1.28	.95									20.40	78.0	11.49	19.8	7.35	6.7	5.11	2.74	450
500	3.19	.82	2.04	.28	1.42	.113	1.04	.06							22.70	98.0	12.77	24.0	8.17	8.1	5.68	2.90	500
550	3.52	.97	2.24	.33	1.56	.135	1.15	.07							24.96	117.0	14.04	28.7	8.99	9.6	6.25	3.96	550
600	3.84	1.14	2.45	.39	1.70	.159	1.25	.08							27.23	137.0	15.32	33.7	9.80	11.3	6.81	4.65	600
650	4.16	1.34	2.65	.45	1.84	.19	1.37	.09									16.59	39.0	10.62	13.2	7.38	5.40	650
700	4.46	1.54	2.86	.52	1.99	.22	1.46	.10									17.87	44.9	11.44	15.1	7.95	6.21	700
750	4.80	1.74	3.06	.59	2.13	.24	1.58	.11	16" PIPE								19.15	51.0	12.26	17.2	8.50	7.12	750
800	5.10	1.90	3.26	.66	2.27	.27	1.67	.13									20.42	57.0	13.07	19.4	9.08	7.96	800
850	5.48	2.20	3.47	.75	2.41	.31	1.79	.16	1.36	.08							21.70	64.0	13.89	21.7	9.65	8.95	850
900	5.75	2.46	3.67	.83	2.56	.34	1.88	.16	1.44	.084	20" PIPE						22.98	71.0	14.71	24.0	10.20	10.11	900
950	6.06	2.87	3.88	.91	2.70	.38	2.00	.18	1.52	.095									15.52	26.7	10.77	11.20	950
1000	6.38	2.97	4.08	1.03	2.84	.41	2.10	.19	1.60	.10	1.02	.04							16.34	29.2	11.34	12.04	1000
1100	7.03	3.52	4.49	1.19	3.13	.49	2.31	.23	1.76	.12	1.12	.04							17.97	34.9	12.48	14.55	1100
1200	7.66	4.17	4.90	1.40	3.41	.58	2.52	.27	1.92	.14	1.22	.05							19.61	40.9	13.61	17.10	1200
1300	8.30	4.85	5.31	1.62	3.69	.67	2.71	.32	2.08	.17	1.33	.06									14.72	18.4	1300
1400	8.95	5.50	5.71	1.87	3.98	.78	2.92	.36	2.24	.19	1.43	.06	24" PIPE								15.90	22.60	1400
1500	9.58	6.24	6.12	2.13	4.26	.89	3.15	.41	2.39	.21	1.53	.07									17.02	25.60	1500
1600	10.21	7.00	6.53	2.39	4.55	.98	3.34	.47	2.56	.24	1.63	.08			30" PIPE						18.10	26.9	1600
1800	11.50	8.78	7.35	2.95	5.11	1.21	3.75	.58	2.87	.30	1.84	.10	1.28	.04									1800
2000	12.78	10.71	8.16	3.59	5.68	1.49	4.17	.71	3.19	.37	2.04	.12	1.42	.05									2000
2200	14.05	12.78	8.98	4.24	6.25	1.81	4.59	.84	3.51	.44	2.25	.15	1.56	.06									2200
2400	15.32	14.2	9.80	5.04	6.81	2.08	5.00	.99	3.83	.52	2.45	.17	1.70	.07	1.09	.02							2400
2600			10.61	5.81	7.38	2.43	5.47	1.17	4.15	.60	2.66	.20	1.84	.08	1.16	.02							2600
2800			11.41	6.70	7.95	2.75	5.84	1.32	4.47	.68	2.86	.23	1.98	.09	1.27	.03							2800
3000			12.24	7.62	8.52	3.15	6.01	1.49	4.79	.78	3.08	.27	2.13	.10	1.37	.03							3000
3200			13.05	7.8	9.10	3.51	6.68	1.67	5.12	.88	3.27	.30	2.26	.12	1.46	.04							3200
3500			14.30	10.08	9.95	4.16	7.30	1.97	5.59	1.04	3.59	.35	2.49	.14	1.56	.04							3500
3800			15.51	13.4	10.80	4.90	7.98	2.36	6.07	1.20	3.88	.41	2.69	.17	1.73	.05							3800
4200					11.92	5.88	8.76	2.77	6.70	1.44	4.29	.49	2.99	.20	1.91	.07							4200
4500					12.78	6.90	9.45	3.22	7.18	1.64	4.60	.56	3.20	.22	2.04	.08							4500
5000					14.20	8.40	10.50	3.92	8.01	2.03	5.13	.68	3.54	.27	2.26	.09							5000
5500							11.55	4.65	8.78	2.39	5.64	.82	3.90	.33	2.50	.11							5500
6000							12.60	5.50	9.58	2.79	6.13	.94	4.25	.38	2.73	.13							6000
6500							13.65	6.45	10.39	3.32	6.64	1.10	4.61	.45	2.96	.15							6500
7000							14.60	7.08	11.18	3.70	7.15	1.25	4.97	.52	3.18	.17							7000
8000									12.78	4.74	8.17	1.61	5.68	.66	3.64	.23							8000
9000									14.37	5.90	9.20	2.01	6.35	.81	4.08	.28							9000
10000									15.96	7.19	10.20	2.44	7.07	.98	4.54	.33							10000
12000											12.25	3.41	8.50	1.40	5.46	.48							12000
14000											14.30	4.54	9.95	1.87	6.37	.63							14000
16000													11.38	2.40	7.28	.81							16000
18000													12.76	2.97	8.18	1.02							18000
20000													14.20	3.60	9.10	1.23							20000

TABLE 9-8

THEORETICAL HORSE-POWER REQUIRED TO RAISE WATER TO DIFFERENT HEIGHTS

Feet	5	10	15	20	25	30	35	40	45	50	60	75	90	100	125	150	175	200	250	300	350	400	Feet
Gals. per Min.																							Gals. per Min.
5	.006	.012	.019	.025	.031	.037	.044	.05	.06	.06	.07	.09	.11	.12	.16	.19	.22	.25	.31	.37	.44	.50	5
10	.012	.025	.037	.050	.062	.075	.087	.10	.11	.12	.15	.19	.22	.25	.31	.37	.44	.50	.62	.75	.87	1.00	10
15	.019	.037	.056	.075	.094	.112	.131	.15	.17	.19	.22	.28	.34	.37	.47	.56	.66	.75	.94	1.12	1.31	1.50	15
20	.025	.050	.075	.100	.125	.150	.175	.20	.22	.25	.30	.37	.45	.50	.62	.75	.87	1.00	1.25	1.50	1.75	2.00	20
25	.031	.062	.093	.125	.156	.187	.219	.25	.28	.31	.37	.47	.56	.62	.78	.94	1.09	1.25	1.56	1.87	2.19	2.50	25
30	.037	.075	.112	.150	.187	.225	.262	.30	.34	.37	.45	.56	.67	.75	.94	1.12	1.31	1.50	1.87	2.25	2.62	3.00	30
35	.043	.087	.131	.175	.219	.262	.306	.35	.39	.44	.52	.66	.79	.87	1.08	1.31	1.53	1.75	2.19	2.62	3.06	3.50	35
40	.050	.100	.150	.200	.250	.300	.350	.40	.45	.50	.60	.75	.90	1.00	1.25	1.50	1.75	2.00	2.50	3.00	3.50	4.00	40
45	.056	.112	.168	.225	.281	.337	.394	.45	.51	.56	.67	.84	1.01	1.12	1.41	1.69	1.97	2.25	2.81	3.37	3.94	4.50	45
50	.062	.125	.187	.250	.312	.375	.437	.50	.56	.62	.75	.94	1.12	1.25	1.56	1.87	2.19	2.50	3.12	3.75	4.37	5.00	50
60	.075	.150	.225	.300	.375	.450	.525	.60	.67	.75	.90	1.12	1.35	1.50	1.87	2.25	2.62	3.00	3.75	4.50	5.25	6.00	60
75	.093	.187	.281	.375	.469	.562	.656	.75	.84	.94	1.12	1.40	1.69	1.87	2.34	2.81	3.28	3.75	4.69	5.62	6.56	7.50	75
90	.112	.225	.337	.450	.562	.675	.787	.90	1.01	1.12	1.35	1.68	2.02	2.25	2.81	3.37	3.94	4.50	5.62	6.75	7.87	9.00	90
100	.125	.250	.375	.500	.625	.750	.875	1.00	1.12	1.25	1.50	1.87	2.25	2.50	3.12	3.75	4.37	5.00	6.25	7.50	8.75	10.00	100
125	.156	.312	.469	.625	.781	.937	1.094	1.25	1.41	1.56	1.87	2.34	2.81	3.12	3.91	4.69	5.47	6.25	7.81	9.37	10.94	12.50	125
150	.187	.375	.562	.750	.937	1.125	1.312	1.50	1.69	1.87	2.25	2.81	3.37	3.75	4.69	5.62	6.56	7.50	9.37	11.25	13.12	15.00	150
175	.219	.437	.656	.875	1.093	1.312	1.531	1.75	1.97	2.19	2.62	3.28	3.94	4.37	5.47	6.56	7.66	8.75	10.94	13.12	15.31	17.50	175
200	.250	.500	.750	1.000	1.250	1.500	1.750	2.00	2.25	2.50	3.00	3.75	4.50	5.00	6.25	7.50	8.75	10.00	12.50	15.00	17.50	20.00	200
250	.312	.625	.937	1.250	1.562	1.875	2.187	2.50	2.81	3.12	3.75	4.69	5.62	6.25	7.81	9.37	10.94	12.50	15.72	18.75	21.87	25.00	250
300	.375	.750	1.125	1.500	1.875	2.250	2.625	3.00	3.37	3.75	4.50	5.62	6.75	7.50	9.37	11.25	13.12	15.00	18.75	22.50	26.25	30.00	300
350	.437	.875	1.312	1.750	2.187	2.625	3.062	3.50	3.94	4.37	5.25	6.56	7.87	8.75	10.94	13.12	15.31	17.50	21.87	26.25	30.62	35.00	350
400	.500	1.000	1.500	2.000	2.500	3.000	3.500	4.00	4.50	5.00	6.00	7.50	9.00	10.00	12.50	15.00	17.50	20.00	25.00	30.00	35.00	40.00	400
500	.625	1.250	1.875	2.500	3.125	3.750	4.375	5.00	5.62	6.25	7.50	9.37	11.25	12.50	15.62	18.75	21.87	25.00	31.25	37.50	43.75	50.00	500

There are several kinds of sharp-edged weirs that are commonly used. A few of these are shown below with the formula for solution.

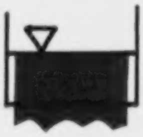
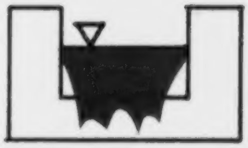
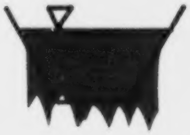
Type of Weir	Shape	Formula for Q
Rectangular, suppressed		$Q = 3.33\ Lh^{3/2}$
Rectangular, contracted		$Q = 3.33\ \frac{(L-2h)}{10}\ h^{3/2}$
Cipoletti, trapezoidal		$Q = 3.33\ Lh^{3/2}$
90° V-notch		$Q = 2.5\ h^{2.5}$

Figure (9-19)

The Parshall flume is advantageous for measuring sewage flows because it requires small loss of head for operation and it allows solids to pass through with relative ease. The flume is illustrated in Figure 9-20 and the flow is indicated by the depth of sewage at the point indicated upstream from the crest. Parshall has determined the relationship between H_a and discharge when the flumes were constructed according to the dimensions given in Table 9-9. For free flow the discharge rates versus head are given in Table 9-10.

Free flow is the condition under which the rate of discharge is dependent solely on the crest length and the depth of water at the gauge point H_a, in the converging section. Free flow should occur in the ratio of H_a (head at the downstream end of the throat section) to H_a is 0.7 or less for the 1- to 8-foot flumes or 0.6 for the 3-, 6-, and 9-inch flumes.

The venturi meter, Figure 9-21, may be used with screened sewage and sludge but it is desirable that it be of the eccentric type in order to prevent accumulation of solids just upstream of the throat. The pressure taps are kept clean with a small flow of clear water. The calibration supplied by the manufacturer will give reasonable accuracy if solids have not accumulated on the meter walls.

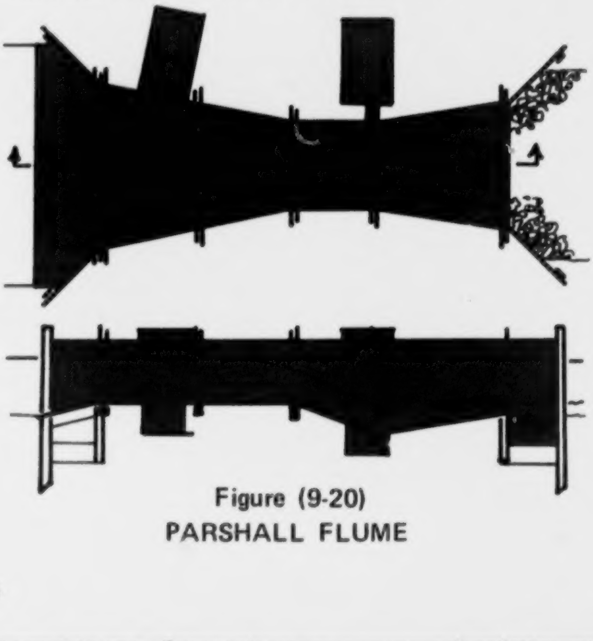


Figure (9-20)
PARSHALL FLUME

Figure (9-21)

VENTURI METER

TABLE 9-9

DIMENSIONS AND CAPACITIES OF THE PARSHALL FLUME, FOR VARIOUS THROAT WIDTHS, W

W		*A*		*2/3A*		*B*		*C*		*D*		*E*		*F*	
Ft.	*In.*	*Ft.*	*In.*	*Ft.*	*In.*	*Ft.*	*In.*	*Ft.*	*In.*	*Ft.*	*In.*	*Ft.*	*In.*	*Ft.*	*In.*
0	3	1	6-3/8	1	1/4	1	6	0	7	0	10-3/16	2	0	0	6
0	6	2	7/16	1	4-5/16	2	0	1	3-1/2	1	3-5/8	2	0	1	0
0	9	2	10-5/8	1	11-1/8	2	10	1	3	1	10-5/8	2	6	1	0
1	0	4	6	3	0	4	4-7/8	2	0	2	9-1/4	3	0	2	0
1	6	4	9	3	2	4	7-7/8	2	6	3	4-3/8	3	0	2	0
2	0	5	0	3	4	4	10-7/8	3	0	3	11-1/2	3	0	2	0
3	0	5	6	3	8	5	4-3/4	4	0	5	1-7/8	3	0	2	0
4	0	6	0	4	0	5	10-5/8	5	0	6	4-1/4	3	0	2	0

G		*K*	*W*		*N*	*R*		*M*		*P*		*X*	*Y*	*Free-Flow Capacity Minimum*	*Maximum*
Ft.	*In.*	*In.*	*Ft.*	*In.*	*In.*	*Ft.*	*In.*	*Ft.*	*In.*	*Ft.*	*In.*	*In.*	*In.*	*Sec.-ft.*	*Sec.-ft.*
1	0	1	0	3	2-1/4	1	4	1	0	2	6-1/4	1	1-1/2	0.03	1.9
2	0	3	0	6	4-1/2	1	4	1	0	2	11-1/2	2	3	.05	3.9
1	6	3	0	9	4-1/2	1	4	1	0	3	6-1/2	2	3	.09	8.9
3	0	3	1	0	9	1	8	1	3	4	10-3/4	2	3	.11	16.1
3	0	3	1	6	9	1	8	1	3	5	6	2	3	.15	24.6
3	0	3	2	0	9	1	8	1	3	6	1	2	3	.42	33.1
3	0	3	3	0	9	1	8	1	3	7	3-1/2	2	3	.61	50.4
3	0	3	4	0	9	2	0	1	6	8	10-3/4	2	3	1.3	67.9

TABLE 9-10

FREE-FLOW DISCHARGE TABLE FOR PARSHALL FLUME

Head H_a (Feet)	*Discharge, Q, for Throat Widths, W, of*							
	3 Inches	*6 Inches*	*9 Inches*	*1 Foot*	*1.5 Feet*	*2 Feet*	*3 Feet*	*4 Feet*
	Second-feet	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*
0.10	0.028	0.05	0.09	0.11	0.15	-------	-------	-------
.12	.037	.07	.12	.14	.21	-------	-------	-------
.14	.047	.09	.15	.18	.27	-------	-------	-------
.16	.058	.11	.19	.23	.34	.47	.68	-------
.18	.070	.14	.22	.29	.42	.56	.82	-------
.20	.082	.16	.26	.35	.51	.66	.97	1.26
.22	.095	.19	.30	.40	.59	.77	1.12	1.47
.24	.109	.22	.35	.46	.67	.88	1.28	1.69
.26	.124	.25	.39	.51	.76	.99	1.46	1.91
.28	.138	.28	.44	.58	.85	1.11	1.64	2.15
.30	.154	.31	.49	.64	.94	1.24	1.82	2.39
.32	.170	.34	.54	.71	1.04	1.37	2.02	2.65
.34	.187	.38	.59	.77	1.14	1.40	2.22	2.92
.36	.205	.41	.64	.84	1.25	1.64	2.42	3.20
.38	.22	.45	.70	.92	1.36	1.79	2.64	3.48
.40	.241	.48	.76	.99	1.47	1.93	2.86	3.77
.42	.260	.52	.81	1.07	1.58	2.09	3.08	4.07
.44	.279	.56	.87	1.15	1.70	2.24	3.32	4.38
.46	.299	.61	.94	1.23	1.82	2.40	3.56	4.70
.48	.319	.65	1.00	1.31	1.94	2.57	3.80	5.03
.50	.339	.69	1.06	1.39	2.06	2.73	4.05	5.36
.52	.361	.73	1.13	1.48	2.19	2.90	4.31	5.70
.54	.382	.78	1.20	1.57	2.32	3.08	4.57	6.05
.56	.404	.82	1.26	1.66	2.45	3.26	4.84	6.41
.58	.427	.87	1.33	1.75	2.59	3.44	5.11	6.77
.60	.450	.92	1.40	1.84	2.73	3.62	5.39	7.15
.62	.474	.97	1.48	1.93	2.87	3.81	5.68	7.53
.64	.497	1.02	1.55	2.03	3.02	4.01	5.97	7.91
.66	.522	1.07	1.63	2.13	3.17	4.20	6.26	8.31
.68	.546	1.12	1.70	2.23	3.31	4.40	6.56	8.71
.70	.571	1.17	1.78	2.33	3.46	4.60	6.86	9.11
.72	.597	1.23	1.86	2.43	3.62	4.81	7.17	9.53
.74	.623	1.28	1.94	2.53	3.77	5.02	7.49	9.95
.76	.649	1.34	2.02	2.63	3.93	5.23	7.81	10.4
.78	.675	1.39	2.10	2.74	4.09	5.44	8.13	10.8
.80	.702	1.45	2.18	2.85	4.26	5.66	8.46	11.3
.82	.730	1.50	2.27	2.96	4.42	5.88	8.79	11.7
.84	.757	1.56	2.35	3.07	4.59	6.11	9.13	12.2
.86	.786	1.62	2.44	3.18	4.76	6.33	9.48	12.6
.88	.814	1.68	2.52	3.29	4.93	6.56	9.82	13.1

CHEMISTRY OF WASTE TREATMENT PROCESSES

The word "chemistry" often causes the operator to turn to another section because he feels that the study of chemistry is beyond his understanding. This section is written to explain some of the chemical language in a way that will give a basis for reading more detailed work in "Standard Methods for the Examination of Water and Wastewater." It will cover some explanations of units, fundamental rules, formulas and equations, reactions and method of expressing results.

1. **Units of Measurement.** In general, units are in the metric system with only a few of the common English terms being used. A conversion table for the more common units is included at the end of this section.

Temperature is perhaps the most common measurement which involves two systems of measurement, degrees Centigrade and degrees Fahrenheit. In laboratory work Centigrade is commonly used, but the public uses Fahrenheit so it is often necessary to convert. The following schematic and examples illustrate the conversion:

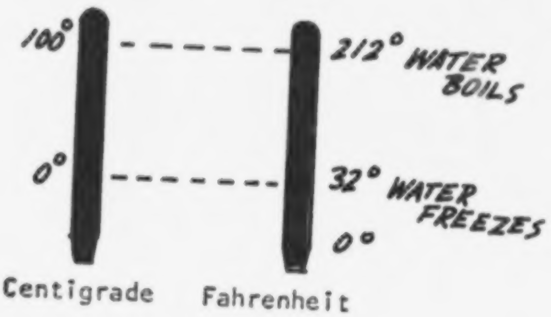


Figure (9-22)

Centigrade

To convert from °F to °C,

subtract 32°F and divide by 1.8 or $\frac{9}{5}$

Example

$68°F - 32°F = 36°F$

$\frac{36}{1.8} = 20°C$ or $36 \times \frac{5}{9} = 20°C$

Fahrenheit

To convert from °C to °F,

multiply by 1.8 and add 32
or multiply by $\frac{9}{5}$ and add 32

Example

$20°C \times 1.8 = 36$

$36 + 32 = 68°F$

or $20°C \times \frac{9}{5} = 36$

$36 + 32 = 68°F$

2. **Definitions.** To converse in the field of chemistry, one must deal with a common language. The following definitions are designed to show a portion of the language:

ACID. A substance which gives up protons (H^+) to another substance. Acids may be molecules, positive ions, or negative ions (NH_3, H_2O, NH_4^+, and HSO_4^-).

ATOM. Smallest particle of an element which is capable of entering into a chemical reaction.

ATOMIC NUMBER. (Symbol: Z) Number of protons in the nucleus. Number of positive charges on the nucleus.

ATOMIC WEIGHT. The weighted mean of the masses of the neutral atoms of an element expressed in atomic weight units.

ANION. Negatively charged ion.

ANODE. Positive electrode, attracts cations (positive charges).

ALPHA PARTICLE. A helium nucleus, consisting of two protons and two neutrons, with a double positive charge.

BASE. A molecule or ion that will combine with a proton. (H_2O, NH_3, OH^-, and SO_4^-)

BETA PARTICLE. Charged particle emitted from the nucleus of an atom and having a mass and charge equal in magnitude to those of the electron.

CALORIE. (Cal.) Amount of heat necessary to raise the temperature of one gram of water 1°C (from 14.5°C to 15.5°C).

CATHODE. Negative electrode, attracts anions.

CATION. Positively charged ion.

COMPOUND. A distinct substance formed by a union of two or more ingredients in definite proportions by weight.

ELECTRODE. Either terminal of an electrical apparatus.

ELECTRON. Negatively charged particle which is a constituent of every neutral atom.

ELEMENT. Pure substance consisting of atoms of the same atomic number which cannot be decomposed by ordinary chemical means.

GAMMA RAY. Short wavelength electromagnetic radiation of nuclear origin with a range of wave lengths from about 10^{-8} to 10^{-11} cm, emitted from the nucleus.

GRAM ATOMIC WEIGHT. A mass in grams numerically equal to the atomic weight of an element.

GRAM-EQUIVALENT WEIGHT. The mass in grams of a substance which will react with one gram atomic weight of hydrogen or one-half gram atomic weight of oxygen.

GRAM MOLECULAR WEIGHT. (GRAM-MOLE) Mass in grams numerically equal to the molecular weight of a substance.

ION. Atomic particle, atom, or chemical radical bearing an electrical charge, either negative or positive.

IONIZATION. The process or result of any process by which a neutral atom or molecule acquires either a positive or negative charge.

MICRON. Unit of length equal to 10^{-6} meters.

MOLECULAR WEIGHT. The sum of the atomic weights of all the atoms in a molecule.

MOLECULE. Ultimate unit quantity of a compound which can exist by itself and retain all the properties of the original substance.

NORMAL SOLUTION. One equivalent weight of solute in one liter of solution.

NUCLEUS. That part of an atom in which the total positive electric charge and most of the mass are concentrated.

PH. Logarithm of the reciprocal of the hydrogen ion concentration. pH for water = 7.0.

SALT. Crystalline ionic compound; when dissolved in water, conducts electricity due to free movement of ions.

SPECTRUM. A visual display, a photographic record, or a plot of the distribution of the intensity of radiation of a given kind as a function of its wavelength, energy, frequency, momentum, mass, or any related quantity.

VALENCE. Number representing the combining or displacing power of an atom; number of electrons lost, gained or shared by an atom in a compound; number of hydrogen atoms with which an atom will combine or which it will displace.

These definitions, coupled with the Periodic Chart of the Elements at the end of this section, are the basis for the chemistry which is used in Sewage Works.

3. **Fundamental Rules, Formulas, Equations, and Reactions.** Chemistry deals with three states of matter: solid, liquid and gas. A solid is a rigid mass that takes on definite form. Liquids flow and will assume the shape of the container. They have definite volume. Gasses, on the other hand, will diffuse and fill any container in which they are placed. All matter, whether solid, liquid or gas, is made up of one or more elements. These elements are shown on the periodic chart as symbols such as O for oxygen, H for hydrogen, S for sulfur. Table 9-11 indicates the elements with their symbols, atomic numbers and atomic weights. The atomic number indicates the number of protons in the nucleus and the place of the element on the periodic chart. The atomic weight indicates the relative weight of the element as compared with oxygen as 16.

Elements combine in definite proportions to form compounds. The make-up of a compound is indicated by its formula, which is a combination of the symbols of the elements. Thus, water is composed of two atoms of hydrogen and one atom of oxygen, and its formula is H_2O. Sulfuric acid is composed of two atoms of hydrogen, one of sulfur and four of oxygen, and its formula is H_2SO_4. The symbol for an element indicates one atom and, likewise, the formula for a compound indicates one molecule. Thus, 2H indicates two atoms of hydrogen, and $2H_2 SO_4$ indicates two molecules of sulfuric acid. The molecular weight of a compound is equal to the sum of the atomic weights of the atoms in the molecule. Thus, a molecule of water (H_2O) has a molecular weight of $(2 \times 1.008) + 16.00 = 18.016$.

The combining power or ratio in which atoms of an element combine with atoms of other elements is called valence. The valence of hydrogen is one. The valence of the other elements is determined by an examination of the formula of a compound in which the element occurs. Oxygen, for instance, has a valence of two since it occurs in water combined with two hydrogen atoms (H_2O). Chlorine has a valence of one since it occurs in HC1 combined with one hydrogen atom.

Not all elements will combine to form compounds. For instance, hydrogen will combine with oxygen, chlorine and nitrogen but will not combine with metals such as iron, calcium and sodium. The bond or force which holds elements together in compounds is electrical in nature, and elements having like electrical tendencies will not combine. Thus, hydrogen and the metals are said to have positive electrical tendencies and chlorine, oxygen, etc., negative. The comparative value of these electrical forces constitutes the valence of the atoms. Hydrogen is said to have a positive valence of one, oxygen a negative valence of two, etc. The sum of the positive valences in any compound must be equal to the sum of the negative valences. Thus, in H_2SO_4, the oxygen has a total negative valence of eight and hydrogen positive two, leaving six positive for the sulfur. A few elements assume different valences under different conditions. Carbon may have positive valence of two or four in carbon monoxide (CO) and carbon dioxide (CO_2), respectively. Some elements encountered in water and sewage analysis may have either positive or negative valence. For instance, N has a negative valence of three in NH_3 and a positive valence of four in NO_2.

The atomic and molecular weights are the basis of all quantitative chemical reactions and are used in all quantitative calculations. A knowledge of them is necessary in order to understand the calculations involved in the chemical determinations. For example, the formula for sulfuric acid is H_2SO_4. The molecular weight of H_2SO_4 and the percentage composition of the elements in this compound may be obtained by referring to the atomic weights as follows:

Hydrogen, 2 atomic weights = 2 x 1.008 = 2.016
Sulfur, 1 atomic weight = 1 x 32.06 = 32.060
Oxygen, 4 atomic weights = 4 x 16.00 = $\underline{64.000}$
Molecular weight = 98.076

The percentage by weight of hydrogen is $\frac{2.016}{98.076} \times 100 = 2.04$

That of sulfur is $\frac{32.06}{98.076} \times 100 = 32.69$

That of oxygen is $\frac{64.00}{98.076} \times 100 = 65.36$

TABLE 9-11

ATOMIC WEIGHTS

Element	*Symbol*	*No.*	*Wt.*	*Element*	*Symbol*	*No.*	*Wt.*
Aluminum	Al	13	26.98	Molybdenum	Mo	42	95.95
Antimony	Sb	51	121.76	Neodymium	Nd	60	144.27
Argon	Ar	18	39.944	Neon	Ne	10	20.183
Arsenic	As	33	74.91	Nickel	Ni	28	58.71
Barium	Ba	56	137.36	Nitrogen	N	7	14.008
Beryllium	Be	4	9.02	Osmium	Os	76	190.2
Bismuth	Bi	83	209.00	Oxygen	O	8	16.00
Boron	B	5	10.82	Palladium	Pd	46	106.4
Bromine	Br	35	79.916	Phosphorus	P	15	30.98
Cadmium	Cd	48	112.41	Platinum	Pt	78	195.09
Calcium	Ca	20	40.08	Potassium	K	19	39.102
Carbon	C	6	12.010	Praseodymium	Pr	59	140.92
Cerium	Ce	58	140.13	Protactinium	Pa	91	231.0
Cesium	Cs	55	132.91	Radium	Ra	88	226.05
Chlorine	Cl	17	35.457	Radon	Rn	86	222.0
Chromium	Cr	24	52.01	Rhenium	Re	75	186.22
Cobalt	Co	27	58.94	Rhodium	Rh	45	102.91
Columbium	Cb	41	92.91	Rubidium	Rb	37	85.48
Copper	Cu	29	63.54	Ruthenium	Ru	44	101.07
Dysprosium	Dy	66	162.51	Samarium	Sm	62	150.35
Erbium	Er	68	167.27	Scandium	Sc	21	44.96
Europium	Eu	63	152.0	Selenium	Se	34	78.96
Fluorine	F	9	19.0	Silicon	Si	14	28.09
Gadolinium	Gd	64	157.26	Silver	Ag	47	107.880
Gallium	Ga	31	69.72	Sodium	Na	11	22.991
Germanium	Ge	32	72.60	Strontium	Sr	38	87.63
Gold	Au	79	197.2	Sulfur	S	16	32.066
Hafnium	Hf	72	178.5	Tantalum	Ta	73	180.95
Helium	He	2	4.003	Tellurium	Te	52	127.61
Holmium	Ho	67	164.94	Terbium	Tb	65	158.93
Hydrogen	H	1	1.0080	Thallium	Tl	81	204.39
Indium	In	49	114.76	Thorium	Th	90	232.04
Iodine	I	53	126.92	Thulium	Tm	69	168.94
Iridium	Ir	77	192.2	Tin	Sn	50	118.70
Iron	Fe	26	55.85	Titanium	Ti	22	47.90
Krypton	Kr	36	83.8	Tungsten	W	74	183.86
Lanthanum	La	57	138.92	Uranium	U	92	238.03
Lead	Pb	82	207.21	Vanadium	V	23	50.95
Lithium	Li	3	6.940	Xenon	Xe	54	131.3
Lutecium	Lu	71	174.99	Ytterbium	Yb	70	173.04
Magnesium	Mg	12	24.32	Yttrium	Y	39	88.92
Manganese	Mn	25	54.93	Zinc	Zn	30	65.38
Mercury	Hg	80	200.61	Zirconium	Zr	40	91.22

TABLE 9-12

FORMULAS, MOLECULAR WEIGHTS, AND EQUIVALENT WEIGHTS OF COMPOUNDS FREQUENTLY CONCERNED IN TREATMENT

Compound	Formula	Molecular Weight	Equivalent Weight
Aluminum sulfate (crystal)	$Al_2(SO_4)_3.18H_2O$	666.0	111.0
Aluminum sulfate (anhydrous)	$Al_2(SO_4)_3$	341.9	57.0
Ammonium alum	$Al_2(SO_4)_3SO_4.24H_2O$	869.9	128.3
Aluminum hydroxide	$Al(OH)_3$	78.0	26.0
Barium carbonate	$BaCO_3$	197.4	98.7
Barium chloride	$BaCl_2$	208.3	104.2
Barium sulfate	$BaSO_4$	233.4	116.7
Calcium	Ca	40.1	20.0
Calcium bicarbonate	$Ca(HCO_3)_2$	162.1	81.0
Calcium carbonate	$CaCO_3$	100.0	50.0
Calcium chloride	$CaCl_2$	111.0	55.5
Calcium hydrate	$Ca(OH)_2$	74.1	37.0
Calcium oxide	CaO	56.1	28.0
Calcium sulfate	$CaSO_4$	136.2	68.1
Calcium phosphate	$Ca_3(PO_4)_2$	310.3	51.7
Ferrous sulfate	$FeSO_4.7H_2O$	278.0	139.0
Magnesium	Mg	24.3	12.15
Magnesium oxide	MgO	40.3	20.15
Magnesium bicarbonate	$Mg(HCO_3)_2$	146.3	73.1
Magnesium carbonate	$MgCO_3$	84.3	42.1
Magnesium chloride	$MgCl_2$	95.2	47.6
Magnesium hydroxide	$Mg(OH)_2$	58.3	29.1
Magnesium phosphate	$Mg_3(PO_4)_2$	263.0	43.8
Magnesium sulfate	$MgSO_4$	120.4	60.2
Silica	SiO_2	60.1	30.0
Sodium	Na	23.0	23.0
Sodium bicarbonate	$NaHCO_3$	84.0	84.0
Sodium carbonate	Na_2CO_3	106.0	53.0
Sodium chloride	NaCl	58.5	58.5
Sodium hydroxide	NaOH	40.0	40.0
Trisodium phosphate (hydrated)	$Na_3PO_4.12H_2O$	380.0	126.3
Disodium phosphate (hydrated)	$Na_2HPO_4.12H_2O$	358.0	119.3
Sodium sulfate	Na_2SO_4	142.0	71.0
Acid Radicals			
Bicarbonate	HCO_3	61.0	61.0
Carbonate	CO_3	60.0	30.0
Carbon dioxide	CO_2	44.0	22.0
Chloride	Cl	35.4	35.4
Hydrate	OH	17.0	17.0
Phosphate	PO_4	95.0	31.7
Sulfate	SO_4	96.0	48.0
Acids			
Carbonic acid	H_2CO_3	62.0	31.0
Hydrochloric acid	HCl	36.4	36.4
Phosphoric acid	H_3PO_4	98.0	32.7
Sulfuric acid	H_2SO_4	98.1	49.0

The chemical reaction and the relative weights of the reacting substances are shown by writing an equation using the formula and molecular weights as follows:

$$\begin{array}{cccc} H_2SO_4 + & 2NaOH \rightarrow & Na_2SO_4 + & 2H_2O \\ 98.08 & 2\times40.0 & 142.06 & 2\times18.02 \end{array}$$

This equation indicates that one molecule of sulfuric acid reacts with two molecules of sodium hydroxide to form one molecule of sodium sulfate and two molecules of water. The number of molecules and molecular weights written below the formulas indicate the weight ratios between the reacting substances. Thus, 98.08 grams (pounds, tons, or other weight units may be used) of sulfuric acid reacts with 80.0 grams of sodium hydroxide to form 142.06 grams of sodium sulfate and 36.04 grams of water. In all cases, knowing the equation for a given reaction, the weight ratios can be determined from the atomic weights of the elements and the formulas of the compounds involved. Since the weight ratios can be found, if the actual weight of any one compound entering into the reaction is known, the weights of all of the other compounds involved can be determined. Table 9–12 includes a number of formulas, molecular weights and equivalent weights of compounds found in waste treatment analyses.

Some of the more important determinations in water and sewage analysis are dependent upon the use of standard solutions. A standard solution is one which contains a known weight of the active substance dissolved in a definite volume of solution. Methods involving the use of such solutions are known as volumetric procedures since the quantitative result is obtained by measurement of volumes.

In the water and sewage laboratory, it is convenient to have solutions of certain definite strengths for use in the different determinations. Such solutions simplify the calculation of results, a decided advantage in routine analysis. They can best be prepared by diluting portions of stock solutions in such a manner as to give solutions of the desired strength.

The strength of a standard solution is usually expressed in terms of the normal system. A normal solution is one which contains one gram-equivalent weight of the active substance in one liter of solution. The gram-equivalent weight of a substance is the weight of that substance which is equivalent to one gram of hydrogen.

There are two general types of chemical reactions encountered in the volumetric determinations used for water and sewage analysis: (1) the simple neutralization or double-decomposition reactions, (2) the reactions involving oxidation and reduction.

The reactions of the first type involve a change in the position of the various atoms and groups making up the reacting substances. The following equations illustrate this type of reaction:

$$HCl + NaOH = NaCl + H_2O$$

$$H_2SO_4 + 2NaOH = Na_2SO_4 + 2H_2O$$

In a reaction of this type, the gram-equivalent weight of the compounds reacting is calculated by dividing the molecular weight of the compound by the number of replaceable hydrogen atoms or their equivalent in that compound.

Thus the gram-equivalent weight of HCl is 36.5, since the molecular weight (36.5) is divided by 1, because there is one replaceable hydrogen. The gram-equivalent weight of H_2SO_4 is one-half its molecular weight, or 49 because there are two replaceable hydrogens. In NaOH one Na can be replaced by one H and is equivalent to one atom of hydrogen. Therefore, the gram-equivalent weight of NaOH is 40 (molecular weight divided by 1).

$$\frac{\text{Molecular weight of a substance}}{\text{No. of replaceable hydrogen atoms or their equivalent}} = \text{Gram-equivalent weight of the substance}$$

The second type of reaction, oxidation-reduction, is illustrated by the following equation:

$$2KMnO_4 + 5H_2C_2O_4 + 3H_2SO_4 = 2MnSO_4 + K_2SO_4 + 10CO_2 + 8H_2O$$

A study of the equation will show that there is more involved than a simple rearrangement of atoms and groups. Mn, for instance, has a positive valence of seven in $KMnO_4$, but only two in $MnSO_4$. The Mn has lost five positive valences (has been reduced) and the $KMnO_4$ has a change in valence of five. Likewise, each C atom in $H_2C_2O_4$ has a valence of positive three and in CO_2 a valence of positive four. The compound $H_2C_2O_4$ has, therefore, a change in positive valence of two (one for each of the two C atoms).

The gram-equivalent weight of a compound entering into an oxidation-reduction reaction is equal to its molecular weight divided by the change in valence of that compound.

$$\frac{\text{Molecular weight}}{\text{Change in valence}} = \text{Gram-equivalent weight}$$

The gram-equivalent weight of $KMnO_4$ is 31.6 (158 divided by 5) and of $H_2C_2O_4$ is 45 (90 divided by 2).

The normality of a standard solution is the ratio of the weight in grams of the substance in one liter to the gram-equivalent weight.

$$\frac{\text{Weight in grams per liter}}{\text{Gram-equivalent weight}} = \text{Normality (N)}$$

Solutions of equal normalities are equal in their reacting value, volume for volume. For example, a volume of 0.1N hydrochloric acid will react with the same volume of 0.1N sodium hydroxide.

The use of normalities simplifies the calculations necessary in obtaining the results of a volumetric analysis. For example, a sample of a solution of iodine is titrated with 0.1N sodium thiosulfate. Ten milliliters of the thiosulfate are required to react with the iodine. It can then be assumed that the amount of iodine present was that which would be contained in 10 mls of a 0.1N iodine solution. The equivalent weight of iodine is 126.9. One liter of 0.1N iodine would contain 12.69 grams of iodine or 10 mls would contain 0.1269 gram. Thus, the sample used contained 0.1269 gram of iodine.

4. **Ionization of Chemical Particles.** Many compounds when dissolved in water will dissociate into a positively charged ion called the cation, and a negatively charged ion called an anion. This action, called ionization, is a common phenomena as water itself is partially ionzied as are most of the dissolved and suspended solids commonly found in water. An ionized substance will act as a conductor of electricity; the more highly ionized the substance will increase the conductivity. Dry air is a good insulator, but the introduction of charged particles or ions will transform it into a conductor. The Geiger Mueller tube for measuring radioactivity is an adaption of this principle. The theories of coagulation, and of disinfection through chlorination are based upon the theory of ionization.

Although dissociated when dissolved in water, ionizable substances will recombine upon evaporation, allowing them to be separated from the liquid medium mechanically. An example of this is the Total Solids determination.

5. **Acids, Bases, Salts, Neutralization, Law of Mass Action.** An acid is a compound that ionizes in water, releasing hydrogen ions. Hydrochloric acid (HCl) becomes $H^+ + Cl^-$. The stronger the acid is, the more hydrogen ions will be released for a given amount of acid. Measurement of the concentration of the hydrogen ions in solution can be determined by the pH test, which will be discussed later. Acids may be mineral such as sulfuric, or organic, such as acetic. Acids are formed in the early stages of anaerobic decomposition of organic matter as occurs in a sludge digester. The measure of organic acids in a digester can be used as an indicator of the stage of digestion. A "stuck" digester is one in which decomposition has stopped at the acid phase.

A base is a compound of a metal and hydroxyl radical. The hydroxyl radical or group $(OH)^-$ consists of an atom of oxygen and one of hydrogen and will ionize in water as a single ion. It carries a negative charge, thus is an anion. Bases are commonly called alkalies. Examples are slaked lime, $Ca(OH)_2$; and sodium hydroxide, NaOH. $Ca(OH)_2$ in water becomes $Ca^{++} + 2(OH)^-$.

$$HCl + NaOH \rightarrow NaCl \text{ (salt)} + H_2O$$

The standardization of solutions in the laboratory is an application of the principle of neutralization.

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Reactions between interacting substances occur at rates that are dependent on ratios of molar concentration of the substances. Most substances react in a reversible manner such that the reaction equation can be written for substances A and B giving substances C and D:

$$A + B \rightleftarrows C + D$$

At the start of the reaction, only substances A and B are present. These react at a certain rate to give C and D. As C and D are produced, A and B decrease. The law of mass action indicates the relative amounts of A, B, C, and D in moles per liter when the substances are in equilibrium:

$$K = \frac{[C][D]}{[A][B]}$$

where K = equilibrium constant
[ ] = molar concentration of the substance in moles per liter

If more than one mole is involved for any of the substances, then the concentration of that substance is raised to the power of the number of moles involved. For example:

$$A + 2B \rightleftarrows 3C + D$$

$$K = \frac{[C]^3[D]}{[A][B]^2}$$

Most quantitative chemistry is based on this law even though it may not be directly used in the analyses which are being conducted.

6. **Hydrogen Ion Concentration, pH.** Water dissociates slightly into hydrogen ions (H^+) and hydroxyl ions (OH^-): $H_2O \rightleftarrows H^+ + OH^-$.

The mass action constant for the equilibrum is:

$$\frac{[H^+][OH^-]}{[H_2O]} = K$$

where [ ] are in moles per liter

but water concentration is omitted in equilibrium constant formulations and the equation reduces to:

$$\begin{aligned}[H^+][OH^-] &= Kw = \text{ion-product constant of water} \\ &= 1.0 \times 10^{-14} \text{ at } 25^\circ C \\ &= 1.2 \times 10^{-15} \text{ at } 0^\circ C \\ &= 5.8 \times 10^{-13} \text{ at } 100^\circ C\end{aligned}$$

At $25^\circ C$ .. $[H^+] = 1.0 \times 10^{-7}$ = Hydrogen ion concentration in moles/liter

$[OH^-] = 1.0 \times 10^{-7}$ = Hydroxyl ion concentration in moles/liter

or written out $[H^+] = 0.0000001$ moles/liter

This is difficult to write so it was suggested that a logarithmic system be used. The result was called the power of the hydrogen ion concentration (potenz H) which was subsequently shortened to pH. pH was defined as the common logarithm of the reciprocal of the hydrogen ion concentration so that the pH of water was:

$$p^h_w = \log \frac{1}{[H^+]} = \log \frac{1}{10^{-7}} = 7$$

Any acidic solution approached zero and an alkaline approached 14. The sum of the hydrogen ion and hydroxyl ion concentrations always equalled 10^{-14}, and pH and pOH equalled 14.

pH can be measured either colorimetrically or electrometrically. In sewage and other colored wastes there is interference from color, turbidity, high saline content, colloidal matter, free chlorine and various oxidants or reductants. The indicators react and follow the law of mass action as follows:

$HIn \quad [H^+][In^-]$ where HIn = Indicator

$[H^+]$ = Hydrogen ion concentration

$[In^-]$ = Indicator ion concentration

If we let HIn = yellow color and $[In^-]$ = red color for convenience, then:

$$\frac{(H^+) \qquad (Red)}{(Yellow)} = K_{HIn} \qquad \text{or} \qquad (H^+) = \frac{(yellow)}{(red)} = K_{HIn}$$

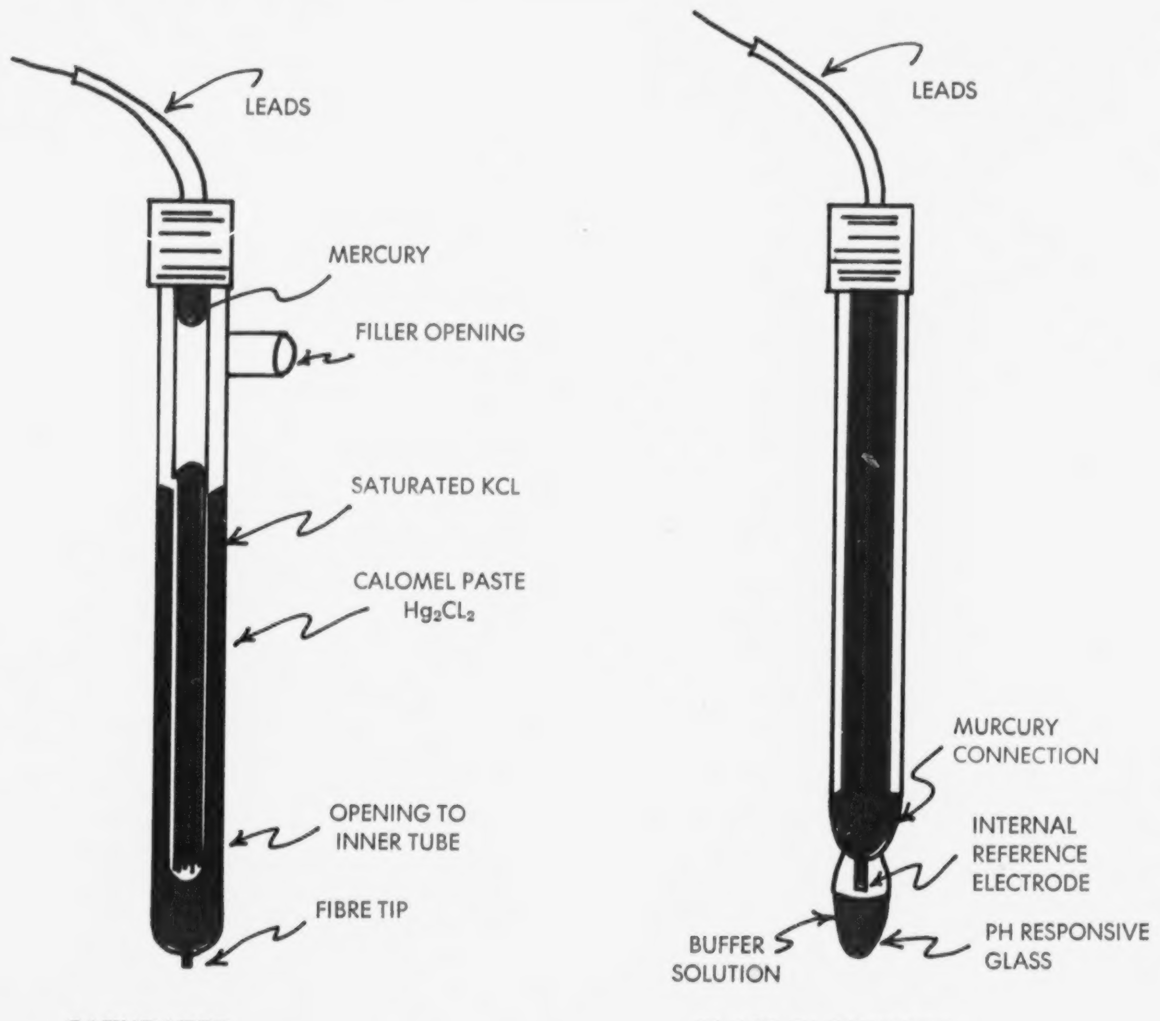
Arranging the equation in tabular form and varying (H^+) the equation becomes:

	(H^+)	(HIn) Yellow	(In^-) Red	Color to Average Eye
	100 × K_{HIn}	0.99	0.01	yellow
	10 × K_{HIn}	0.91	0.09	yellow-red tint
Transition	1 × K_{HIn}	0.50	0.50	orange
Range	0.01 × K_{HIn}	0.09	0.91	red-yellow tint
	0.91 × K_{HIn}	0.01	0.99	red

Chemists take advantage of the preceding reaction with a number of indicator solutions. The following are a few of the popular indicators:

Trade Name	Acid Color	Basic Color	Transition Range (pH)
Methyl Orange	Red	Orange-Yellow	3.1 - 4.6
Bromophenol Blue	Yellow	Blue-Violet	3.0 - 4.6
Methyl Red	Red	Yellow	4.2 - 6.3
Bromothymol Blue	Yellow	Blue	6.0 - 7.6
Thymol Blue	Yellow	Blue	8.0 - 9.6
Phenolphthalein	Colorless	Red	8.0 - 9.8
Thymolphthalein	Colorless	Blue	9.4 -10.6

The electrometric techniques are based on the standard method of using a glass electrode system where 1 pH unit produces an electrical charge of 59.1 millivolts at 25°C. Temperature is the major interference. A standard saturated calomel electrode is used as a reference electrode. This has an emf at 25°C of 0.2415 volts. The following sketch shows schematically the calomel and glass electrodes:


LEADS
MERCURY
FILLER OPENING
SATURATED KCL
CALOMEL PASTE
Hg_2Cl_2
OPENING TO
INNER TUBE
FIBRE TIP
LEADS
MURCURY
CONNECTION
INTERNAL
REFERENCE
ELECTRODE
BUFFER
SOLUTION
PH RESPONSIVE
GLASS

SATURATED
CALOMEL ELECTRODE

GLASS ELECTRODE

Figure (9-23)

The accuracy of the electrometric system is in the order of 0.05 to 0.10 pH unit if care is taken to calibrate the instrument with buffers at pH 4, 7, and 9. It is a delicate instrument and must be kept clean and must be handled with care during both use and storage.

7. **Expression of Results.** Results are generally expressed as milligrams per liter (mg/1) of a certain substance. In the dissolved oxygen test, for example, results are in terms of mg/l of O_2 dissolved in the water. Nitrogen may be expressed as mg/1 of NO_3, NO_2, or NH_3, or calculations can be made to put the value in terms of available nitrogen as N.

A few of the more commonly used conversion units used in water and waste chemistry are shown in Table 9-13. Page 239 contains a periodic chart of the elements.

Recent literature has used both parts per million (ppm) and mg/l interchangeably. This is not entirely correct because ppm is pounds of substance per one million pounds of water. Milligrams per liter is a weight-volume ratio. However, the values are so close that for all practical purposes they can be used as synonyms.

Significant figures are important in expressing results. All of the digits in a reported result are expected to be known definitely, except for the last digit, which may be in doubt. A report should only include figures that are justified by the accuracy of the work.

TABLE 9-13
CONVERSION UNITS FOR CHEMISTRY

1 inch (in)	2.54 centimeters (cm)
1 meter (m)	39.37 inches (in)
1 gallon (gal)	231 cubic inches (in^3) 0.1337 ft^3 3.78533 liters (l)
1 gal of water	8.34 lb at standard temperature and pressure
1 pound (lb)	453.6 grams (gm)
1 kilogram (kg)	2.205 lb
1 atmosphere (atm)	14.697 psi at sea level 33.9 ft of head water 29.92 in of mercury
1 grain per gallon (gpg)	17.15 parts per million (ppm) 142 lb per million gal
1 gram mole of gas	22.4 liter (l)
1 pound mole of gas	359 ft^3
1 milligram per liter (mg/l)	1 part per million (ppm)

Periodic table

PERIODIC TABLE OF THE ELEMENTS

Ia	IIa	IIIb	IVb	Vb	VIb	VIIb	VIII			Ib	IIb	IIIa	IVa	Va	VIa	VIIa	0
1 **H** 1.0080																1 **H** 1.0080	2 **He** 4.003
3 **Li** 6.940	4 **Be** 9.013											5 **B** 10.82	6 **C** 12.011	7 **N** 14.008	8 **O** 16.000	9 **F** 19.00	10 **Ne** 20.183
11 **Na** 22.991	12 **Mg** 24.32											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.975	16 **S** 32.066	17 **Cl** 35.457	18 **Ar** 39.944
19 **K** 39.100	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.90	23 **V** 50.95	24 **Cr** 52.01	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.94	28 **Ni** 58.71	29 **Cu** 63.54	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.60	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.916	36 **Kr** 83.80
37 **Rb** 85.48	38 **Sr** 87.63	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.95	43 **Tc** 99 *	44 **Ru** 101.1	45 **Rh** 102.91	46 **Pd** 106.4	47 **Ag** 107.880	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.70	51 **Sb** 121.76	52 **Te** 127.61	53 **I** 126.91	54 **Xe** 131.30
55 **Cs** 132.91	56 **Ba** 137.36	57 **La** 138.92	72 **Hf** 178.50	73 **Ta** 180.95	74 **W** 183.86	75 **Re** 186.22	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.09	79 **Au** 197.0	80 **Hg** 200.61	81 **Tl** 204.39	82 **Pb** 207.21	83 **Bi** 208.99	84 **Po** 210.	85 **At** 210 *	86 **Rn** 222.
87 **Fr** 223 *	88 **Ra** 226.05	89 **Ac** 227.0															

LANTHANUM SERIES	58 **Ce** 140.13	59 **Pr** 140.91	60 **Nd** 144.27	61 **Pm** 147 *	62 **Sm** 150.35	63 **Eu** 152.0	64 **Gd** 157.26	65 **Tb** 158.93	66 **Dy** 162.51	67 **Ho** 164.94	68 **Er** 167.27	69 **Tm** 168.94	70 **Yb** 173.04	71 **Lu** 174.99
ACTINIUM SERIES	90 **Th** 232.05	91 **Pa** 231.	92 **U** 238.07	93 **Np** 237*	94 **Pu** 242*	95 **Am** 243*	96 **Cm** 247*	97 **Bk** 249*	98 **Cf** 251*	99 **Es** 254*	100 **Fm** 253*	101 **Md** 256*	102 **No** 253*	

*mass number of most stable known isotope

TABLE 9-14

BIOLOGY

1. **Introduction.** The basic principles of biology begin in a study of simple chemical compounds and their interconnected relationships throughout the multitude of living and dead substances, both plant and animal. Whether this organic matter be the smallest microbes or giant whales of the sea, the rules for chemical reactions within them and about them are the same.

Of the many laws governing chemical reactions there are two which become paramount in importance when considering the disposal and treatment of organic wastes. They are the conservation of energy and the conservation of matter. All chemical changes are accompanied by either the release or absorption of energy in one of its many forms, such as heat, light, or electricity. Some absorb energy; others release it. Thus, the energy involved in chemical changes is neither destroyed nor created, but merely stored or changed to a different form. The weight of matter involved in chemical changes likewise remains the same; it too is neither created nor destroyed, but merely stored or changed to a different form.

Through this fundamental knowledge of chemical conservation it may be clearly seen that the key to successful organic waste decomposition lies in man's ability to enhance natural processes for converting unwanted waste products into compounds either innocuous or beneficial to society. Perhaps the most limiting factor in the complexity of waste treatment is the fact that modern societies have been developed around water-borne sewage. The total mass of actual waste to be treated is much less an obstacle than that of repurifying and disinfecting the gigantic volumes of carrier water.

With such a large volume of water involved there is little choice of waste treatment other than assisting the associated organisms responsible for natural decay and oxidation. Thus, treatment plants built by man are little more than "specialty zoos" with ideally sized and controlled compartments to enhance working conditions for the array of microorganisms, larger invertebrates, and chemical reactions which convert waste to acceptable by-products.

Unfortunately, waste treatment processes have not yet been perfected to a degree where they will remove all of the undesirable additives imparted to the carrier water by the transported wastes. It is the carry over of nutrient substances and essential growth elements in the effluent discharges which causes innumerable water pollution problems in receiving streams. Biological cycles of growth and decay forever go on, and our job is to keep them in balance and harmony with the desires of mankind.

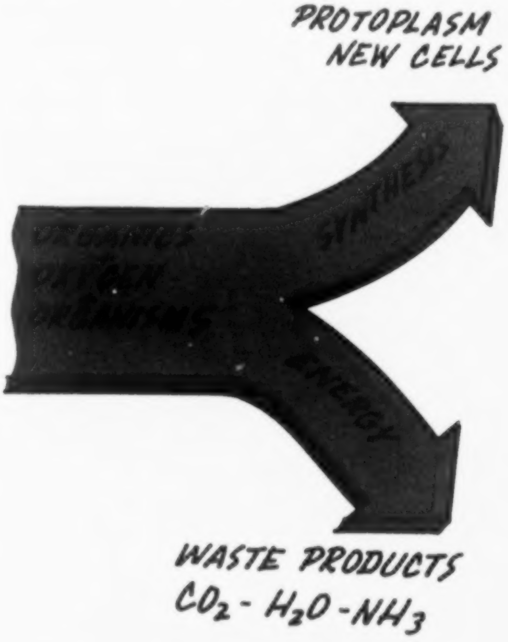
2. **Biochemistry.** Biochemistry is the chemistry involved in the building of living cells, their maintenance, and ultimately the products of their decay after death. The fundamental processes of sewage treatment, where living organisms (mostly bacteria) feed upon sewage, reproduce, give off energy in the form of heat, release by-product gasses, and eventually die, are all biochemical. The life cycles of the organisms go on and on until the residues left behind no longer contain substances that will support bacterial life. The remaining residues are similar to the ash left after burning wood.

Biochemical functions in sewage treatment are generally divided into two types for convenience of application, aerobic and anaerobic. The first requires the presence of free oxygen and the latter requires the absence of free oxygen. The aerobic processes are the most efficient method for reducing the organic content of dilute liquid wastes. Trickling filters, activated sludge, and oxidation lagoons are the three principal methods of aerobic treatment. Though they may differ from each other, they are dependent on the same biochemical principles. Basically, the organisms responsible for treatment possess the ability to decompose complex organic compounds and use the gained energy for their own bodily functions. That part of the organic matter used to produce energy is converted to the essentially stable end products of carbon dioxide, water, and ammonia. The remainder is converted to new cells which can be settled and thereby removed from the liquid before discharge to receiving waters.

There are a great number of organic compounds which can be found in sewage wastes; however, three common groups are of major importance. They are carbohydrates, proteins, and lipids. The carbohydrates, commonly known as simple or complex sugars, are made up of carbon, hydrogen and oxygen. Cane sugar, cereal starch, and lactose from milk are types readily digestible by man, but most carbohydrates in the form of complex cellulose and xylan from plants can be "broken down" only by particularly adapted bacteria.

Proteins are organic substances of large molecular size and contain carbon, hydrogen, oxygen, nitrogen, and sometimes sulfur. They play an important part in the biochemical reactions for among them are enzymes, hormones, antibodies, viruses, and toxins. It is the proteins that release ammonia when oxidized, and the nitrogen from ammonia is a prime source of nutrient to aquatic plants and algae in receiving streams.

Lipids are the fatty substances made up of carbon, hydrogen, and oxygen, but in different combinations than carbohydrates. Biological oxidation, as occurs in the decomposition of organic wastes, results from a complex process where microbial cells (bacteria) break down substances containing carbon, oxygen, hydrogen, nitrogen and sulfur in the presence of free oxygen, and the resulting products are more cells plus carbon dioxide, water, and ammonia. These are stable compounds. Enzymes from proteins generally govern the rate of biological oxidation. They are the catalysts which speed up the reactions without themselves becoming a part of the product. A schematic diagram of the aerobic metabolism process would be as follows:



The anaerobic process is generally used for oxidizing sewage sludge because any gaseous oxygen dissolved in fresh sludge would be quickly depleted. Oxidation of the sludge cannot occur without oxygen, but in this case anaerobic organisms use oxygen contained in organic matter. They take it from nitrites (NO_2), nitrates (NO_3), and sulfates (SO_4). The ultimate end products of their digestion are methane, carbon dioxide, hydrogen sulfide, ammonia and water. It takes two distinct groups of organisms to destroy organic matter and produce methane. The first group of organisms (the acid producing bacteria) degrade organic matter to compounds such as organic acids, alcohols, and aldehydes, while the second group of organisms (the methane producing bacteria) use the end products of the acid-producing bacteria to form methane and carbon dioxide.

Before solid matter can be metabolized by microorganisms it must be rendered soluble so that it can pass through the cell wall and so enter into the biochemical relations of metabolism. The process of liquefication of organic matter is brought about by the secretion of extracellular enzymes that change complex sugars into solutions of simple sugars, proteins to amino acids, and fats to fatty acids. Without such a change to usable solutions it would be impossible to stabilize solid organic matter. The organisms that liquefy solid particles also prepare the organic matter for gasification, and for successful digestion these processes must be kept synchronized and in fine balance. The schematics of anaerobic digestion are illustrated below.

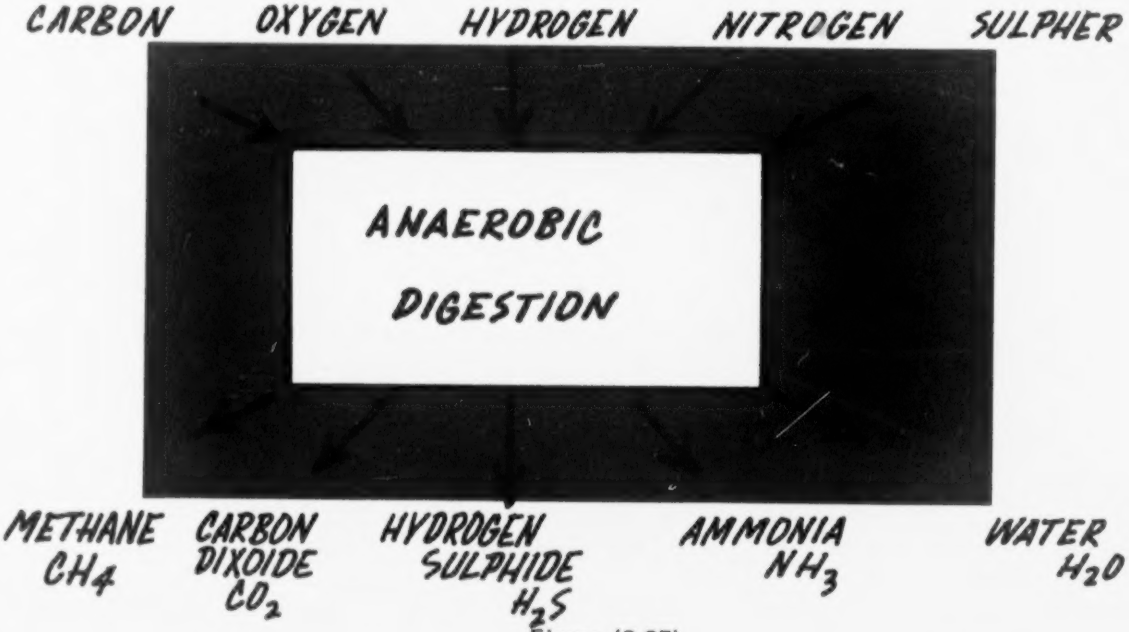


Figure (9-25)

BASIC BACTERIOLOGY FOR SEWAGE WORKS OPERATORS

1. **Introduction.** Bacteria are the most plentiful of all living organisms. They were probably the first living plants, and by their action in decomposing the early rock formations of the earth's crust, development of higher plants and later the development of animal life was made possible. Bacteria are everywhere in our environment. Some are beneficial and make it possible for man's life cycle to continue by reducing dead organic material to plant foods. Others have become parasitic and feed upon other living plants or animals. Some of them are harmful to their host, causing damage or death —these are the pathogenic or disease organisms.

2. **Classification of Bacteria.** All living organisms are classified into an international system so that workers can exchange knowledge without confusion or misunderstanding, regardless of language barriers. An organism is described first in very broad terms, and successively with more and more detail, so that eventually the description fits only that particular organism.

The groups into which the classification system is divided start with the Kingdom. There are only two categories in which an organism can fall: The Plant Kingdom, in which bacteria are commonly placed; and the Animal Kingdom, in which man falls.

Organisms are commonly identified by their generic (genus) and species classification. The generic name, which comes first, is always capitalized and often abbreviated. Both names are underlined or in bold face. For instance, **Escherichia coli** (E. coli) is of the genus **Escherichia** and the **coli** species.

As bacteria are single-celled microscopic organisms, their physical description cannot be in sufficient detail to adequately differentiate the smaller groups of the classification system. It is necessary, then, to use additional tests, such as cultural and chemical. These tests are the tools of the bacteriologist in evaluating sewage treatment, stream pollution, etc.

3. **Classification by Form of Bacteria.** Bacteria are microscopic, single-celled plants. The unit of length by which bacterial size is measured is the micron (1/25,000 of an inch or 1/1,000 of a millimeter. **E. coli,** one of the common indicators of fecal contamination, is about a micron (1/1,000 of a mm) in length. It is obvious that means other than searching with a microscope are needed to detect their presence rapidly but consistently. However, the microscopic examination of cultures is a valuable tool for positive identification of a specific organism.

The shape of bacteria is used as a means of identification. The usual classification by shape is at the bottom of the page.

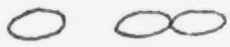
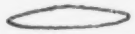
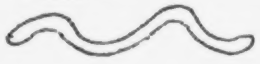
The coccal form may be in single cells, pairs, fours, long or short chains, or clumps. The bacillus though not so varied in its groupings, may be in rods of varying lengths, some easily identifiable and others so short they may be confused with coccal forms.

4. **Classification by Environment**. A second general classification of bacteria is by their dependence or independence upon free oxygen. These groups are divided as follows:

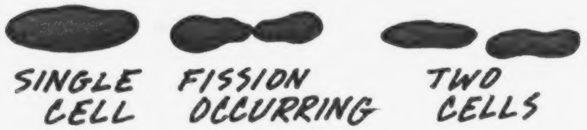
A. Aerobes. Aerobic bacteria require free oxygen to live. Organisms of this type destroy organic matter quickly and without the formation of obnoxious odors. The organisms are the kind that will be found in the growth on the stone of trickling filters in sewage plants or in fast flowing and well aerated streams.

B. Anaerobes. The anaerobic bacteria can break organic material down to release the oxygen bound chemically in the material. They do not require free oxygen and some forms will die in the presence of oxygen. These organisms are found in sludge digestion chambers in sewage plants and sludge banks in streams. They are slower to destroy organic matter than aerobic bacteria, and obnoxious gases are often released during the decomposition process.

C. Facultative. These organisms may be either aerobic or anaerobic. Some prefer free oxygen, though able to live without it. These are called facultative aerobes. Others prefer an oxygen free environment, though able to live with oxygen if necessary. These are the facultative anaerobes.

Form	*Name*	*Example*	*Sketch*
Sphere	Coccus	Streptoccus faecalis	
Rod	Bacillus	Escherichia coli	
Spiral	Spirillum	Treponema pallidum	

5. **Rate of Reproduction of Bacteria.** Bacteria reproduce by binary fission; i.e., the cells divide into two or more organisms. The most important aspect of bacterial reproduction to us is the rate of reproduction, and the factors that will influence it.



The total time for an organism to reproduce and the new generation to reach maturity is termed the generation time. The generation time varies widely according to the type of organism and with the temperature, food supply and other factors of the organism's environment. Given favorable growth conditions, a few, or even a single bacteria can reproduce to a massive population in a short time. Theoretically, a single **E. coli**, with a generation time of 30 minutes, could reproduce to over a million-million in a day's time. Fortunately, optimum conditions and adequate food are not available for indefinite periods; but the point is that phenomenal growth in bacterial population is to be expected under conditions we consider as "normal".

The actual growth rate of bacteria is limited by available food supplies, environment and ultimately their decline and death is brought about by over population and accumulation of waste products.

6. **Effects of Temperature.** The temperature to which bacteria are subjected will have a great deal of effect upon their activity. Each type of organism has a particular range of temperature at which metabolism and reproduction will be at a peak. This is termed the optimum temperature range. Above or below the optimum range the activity of the organism will be reduced until eventually it will stop altogether and the organism dies. Heat is more destructive to organisms than cold. The amount of heat required will vary, however, with moisture and pressure. The higher the humidity and/or pressure, the lower the lethal temperature will be.

Bacteria may be classified, according to their growth at different temperatures, as:

A. Psychrophilic – The Cold Loving Bacteria. These flourish best at temperatures of 15 to 20 degrees Centigrade (59 to 68 degrees Fahrenheit), with a range from zero to 30 degrees Centigrade (32 to 86 degrees Fahrenheit). Psychrophilic bacteria have little importance in sewage treatment other than interest in the survival of a few pathogenic forms. The typhoid bacillus, for instance, can survive for months in ice and return to the viable state when conditions become favorable again.

B. Mesophilic. These organisms grow best at a temperature of 37 degrees Centigrade (98.6 degrees Fahrenheit). Below 32 degrees Centigrade (89.6 degrees Fahrenheit) and above 42 degrees Centigrade (107.6 degrees Fahrenheit), the growth of these bacteria will be increasingly inhibited. Most pathogenic bacteria belong to the mesophilic group, as do most of the putrefactive genera.

C. Thermophilic – Heat Loving Bacteria. Thermophilic bacteria flourish at temperatures of 50 to 55 degrees Centigrade (112 to 121 degrees Fahrenheit), with an extreme range from about 25 to 85 degrees Centigrade (77 to 185 degrees Fahrenheit). Thermophiles have little significance in ordinary sewage treatment.

Generally speaking, bacterial activity, and the rate of decomposition of organic matter, will increase with a rise in temperature within the optimum range of each group.

7. **Growth Media.** Bacteria, like higher forms of life, do not all prefer the same amount nor the same kinds of foods. Some multiply when only minute traces of food are present – others require relatively large amounts.

The types of food for different types of bacteria vary widely. Some can utilize carbon dioxide, water, and inorganic foods, as plants do. Others utilize and ferment sugars. Still others live on proteins or fats. Many organisms have specialized their food preferences to such a degree that this characteristic can be used to differentiate between types. Culture media can be selected in the laboratory that will grow a selected group, or a single species, of bacteria.

The organic content of sewage carries all the essentials for bacterial growth, and under favorable conditions will support huge populations, including some disease-producing species. The importance of adequate sewage disposal upstream from domestic water intakes is of major concern to the water works profession.

8. **Cycle of Nitrogen, Carbon, and Sulfur in Decomposition.** Organic matter is in a constant state of change, passing from living cells of plant or animal composition, through the state of dead and decomposing material, to the more stable state of essential mineral or organic elements. These can in turn be used as building material for plant or animal cells. Bacterial metabolism plays the key role in decaying organic material by freeing the "tied up" compounds for use by new generations of life.

9. **Inhibiting Agents.** Growth of bacteria may be reduced or stopped by changes in the natural environment and by exposing them to chemical agents, the effects of temperature, and removal of

specific foods. Other natural conditions inhibiting growth are light, dryness, and natural enemies.

Light has a destructive effect on most living cells. Except for the few chlorophyl-bearing microorganisms (small plants with green pigment) bacteria are killed rapidly by direct sunlight. The ultraviolet portion of sunlight, in particular, has strong germicidal properties. The value of holding water and wastes for a long period in open shallow ponds has been recognized for many years. Ultraviolet lamps have been used experimentally for treating water and air with good results. The expense involved is quite high in comparison with conventional means, and this method has found little use in practice.

Drying is detrimental to bacterial life, but does not necessarily kill all the organisms. The inhibiting of bacterial action by drying is well known, and many foods were preserved by drying prior to modern refrigeration. Dehydration can be accomplished by air drying or immersion in solutions such as brines or sugars, that will draw water from cellular material by plasmolysis. Some bacteria, when subjected to drying, go into a dormant state and remain inactive, though "alive," for long periods of time. When conditions become more suitable for growth, the cells will regain their activity with little or no change upon their vitality or characteristics. Pure cultures of bacteria are often preserved by a combination freeze-drying technique.

Bacteria have many natural enemies among the higher forms of organisms that reduce their populations. Protozoa, tiny aquatic animal life, prey upon the bacteria for sustenance. Forms of algae, aquatic plant life, will render the environment unfit for bacterial survival by utilizing needed food materials and by release of products toxic to the bacteria.

In our sewage treatment processes, for instance, man has amply tipped the balance of nature in favor of the predators of bacterial life, and increased the rate of bacterial "purification" to many times that in natural environments.

Many chemical agents will kill or inhibit the growth of bacteria. These are known by a variety of terms, such as germicides, bactericides, antiseptics, disinfectants, sterilizing agents, and prophylaxis.

Some of the common chemical agents that are toxic to bacteria are:

A. The Halogen Groups – Chlorine, Iodine and Bromine. Chlorine in particular is in common usage as it is less expensive and is available in several forms. All of the halogens are effective against bacteria in very small dosages.

B. The Phenolic Group – Phenol (Carbolic Acid), the Cresols (e.g. Lysol) and Thymol. These are effective agents for disinfection, but are not used in water or sewage practice because of the odors, and availability of more suitable agents.

C. Metals and Metallic Salts. There are a number of metals that have some germicidal value. Mercury, zinc, silver, copper, and calcium (quick lime) are all effective to some degree. Their use is very limited, however, and are used only in special instances.

10. **Mode of Metabolism.** The intake of food and excretion of waste by bacterial cells and their life process is bacterial metabolism. Since the single-celled bacteria have no intestinal tract their method of food intake and waste excretion is quite different from that of the higher animals. The intake of food into the cell is accomplished by the action of hydrolyzing enzymes which turn the food into liquid form in order that it can be absorbed through the cell wall. Once inside the cell a different type of enzyme called a desmolyzing enzyme turns the food into the material that constitutes the cell body. Waste products are excreted to the outside of the cell and are called toxins. The waste products are the agents responsible for illness caused by the pathogenic forms.

11. **Spore State of Existence.** Certain species of bacteria when exposed to an unfavorable environment adopt a spore state of existence. In the spore state the cell size is reduced in size to a hard core having a relatively thick and tough cell wall. In this form the bacterial cell is extremely tough and hard to kill. When the environment becomes more favorable the cell grows to its original size. Fortunately only a few species of water-borne bacteria are spore formers.

12. **Enteric Bacteria.** There are a number of species of bacteria excreted in the feces of man and the higher animals. Many of these are nonpathogenic. Some are important in the putrefactive process. There are, however, pathogenic forms discharged from diseased persons or animals and all sewage must be regarded as a vehicle of disease organisms. Some of the classical diseases that have been involved in spectacular outbreaks traced to inadequate protection or treatment of a water supply are: typhoid, cholera, and diarrhea and dysentery. Other diseases have been implicated and still others suspected. Testing of sewage so that the presence of each specific disease-producing bacteria could be determined with confidence would be, for practical purposes, impossible. The pathogenic forms are in the vast minority of the total bacterial count in contaminated water, and could easily be missed in sampling. Instead, it is assumed that all contaminated water contains pathogens, and it is common to test for one of the most numerous non-

pathogenic enteric forms, one of the coloform group, **E. coli,** as indication of fecal contamination. This organism makes up a relatively large proportion of the bacterial population of the lower intestines, is more viable than most pathogens, and can be easily detected. **E. coli** is termed an indicator organism, as its presence is considered an indication that fecal matter is present, even in minute quantities. This is not an absolutely true assumption, as there are coliforms other than the ones discharged from intestinal systems, but as most of the group are associated with soil of one kind or the other, the assumption is considered justifiable. There are, of course, specific tests for **E. coli** that can be done if absolute confirmation is desired. Tests for the presence of the coliform group, and **E. coli**, are outlined in **"Standard Methods for the Analysis of Sewage and Industrial Waste"**, Twelfth Edition.

13. **Most Probable Number (MPN).** The test for detection of coliform bacteria in water or sewage shows the presence of these organisms, but not the actual numbers present in the original sample. To count the coliforms present in every sample would be so painstaking and time consuming as to be impractical. Instead, an indirect method is used, based upon a statistical analysis of the painstaking work of other investigators. The Most Probable Number represents the number of coliform organisms that should be present in a sample when certain combination of test results are obtained. Techniques for running these tests may be found in **"Standard Methods".**

14. **Standard Plate Count.** When it is desirable to have a count of the total number of bacteria in a sample, the Standard Plate Count is used. In this procedure, several dilutions of the sample are added to petri dishes of nutrient agar, a culture media that is solid at room temperature but melts with relatively low heat. The inoculated dishes are incubated for either 24 or 48 hours, depending upon the temperature, and then the number of colonies that developed are counted. Counts are recorded with the temperature of incubation, i.e., "150 standard plate count at 20 degrees Centigrade."

15. **Higher Bacteria.** This group of bacteria is characterized by their filamentous, or thread-like form. The higher bacteria are able to break down simple inorganic materials for energy and growth. Forms of particular interest are the sulfur bacteria, and the iron bacteria. The sulfur bacteria flourish in the presence of hydrogen sulfide. Iron bacteria like waters rich in iron, manganese, and organic matter also. These organisms can become nuisance in pipe lines by forming masses that reduce flow in the lines. **Sphaerotilus,** the common sewage slime growth, is a filamentous bacteria.

16. **Other Microscopic Organisms.** In natural purification processes, organisms of higher orders than bacteria play an important role. Some of these are single-celled, and microscopic in size and may be confused with bacteria by the uninitiated.

17. **Protozoa.** These organisms are the one-celled animals. There are three general classes:

A. Amoeboids. Amoeba have no definite shape, and move by forming "false feet." When conditions are not suitable for growth, some amoeba will form cysts, an inactive state in which the organism may be very difficult to kill.

B. Ciliate Protozoa. These forms have many hair-like appendages and use them for locomotion. Ciliates are voracious eaters, preying on both bacteria and organic material. They are aerobic and anaerobic, and facultative species. Protozoa play an important part in reducing bacterial populations in sewage treatment processes, and occur in large numbers in polluted waters.

C. Flagellates. Flagellates are single-celled animals, often found in colonies, who propel themselves with one or more long, whip-like tentacles which look like hairs. Some types have chlorophyl while others are without pigment. As a group, they are very effective users of nutrient from waste solutions.

18. **Algae.** Algae are characterized by their chlorophyl (green) pigmentation which permits them to use sunlight as energy and transform simple carbon dioxide into complex organic material of a carbonaceous form. Thus, they would be found only where light is present. They are very effective in utilizing nutrients in open waters, especially downstream from sewage treatment facilities.

STREAM SANITATION

1. **Introduction.** Stream sanitation, pollution, contamination and clean water are terms that are often used without much thought as to what they really mean. As previously discussed in Chapter VI, the purity or cleanliness of water is a relative or abstract quality. There is no such thing as 100 percent pure water even if it is triple-distilled and deionized. This is true because of water's unique property as a "universal solvent." When water is evaporated from the ocean by the sun's energy, it is fairly clean and remains so until it falls to the surface of land areas as precipitation. Even in its passage through the atmosphere, however, water picks up traces of dust and various gasses such as nitrogen, oxygen, and carbon dioxide. Once water lands on the surface of the earth, more substances are picked up and carried with the water as it flows over the surface of the ground to streams and fi-

nally to the ocean. In general, if the only contamination acquired by water on its return to the ocean were from such naturally occurring sources, most streams would be relatively clean. Unfortunately man's impact on the environment has created significant additional sources of contamination which, if unchecked, can seriously impair water quality in water. For this reason, waste treatment is an important facet of stream sanitation.

It is the responsibility of each plant operator to do his share to minimize the impact of waste loads on receiving streams. The reason for treatment is, of course, to decrease the amount of organic materials, either solids or dissolved, which reaches a stream so that the stream itself will not have to function as a treatment plant. All stream uses are thus benefitted and a cleaner stream is the eventual result.

2. **Stream Depreciation.** For the purposes of better understanding of the whole field of stream sanitation, it may be compared to a bank system having both deposits (credits) and withdrawals (debits). In the case of stream sanitation, the currency or money, so to speak would be represented by the specific stream characteristic being studied. For example, typical currency might, in the case of a specific stream be represented as dissolved oxygen.

As an example, if BOD load is added to a stream, we would have a debit; when oxygen is added we have a credit. As in the case with a bank, a positive balance must, of course, be maintained at all times.

In order to more illustrate this concept, the following example may prove useful. Assume a section of stream which flows past a treatment plant and receives the treated effluent. Also assume that a portion of the stream flow is removed at some point as an irrigation water source and that an industrial waste discharge is added to the stream at another point.

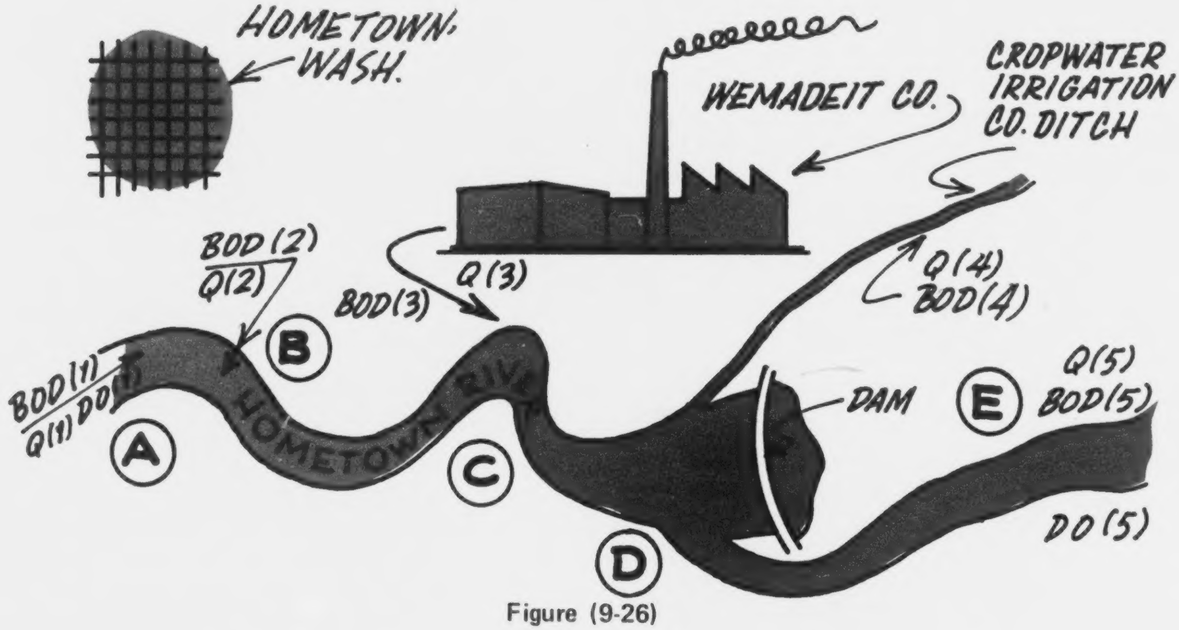


Figure (9-26)

In this example the Hometown River, before it reaches Hometown, Washington has a flow represented by Q(1), a BOD because of upstream uses represented by BOD(1) and a dissolved oxygen content represented by D.O.(1) as the river flows along BOD loads and flows from the city and the Wemadeit Manufacturing Company, represented by BOD(2), BOD(3) and Q(2), Q(3) are added. The river then flows to a dam where the Cropwater Irrigation Co. removes a certain flow and a portion of BOD with that flow from the river. These are represented by Q(4) and BOD(4). The remaining river flow cascades down a spillway and because this causes aeration of the flow a certain dissolved oxygen content, represented by DO(2) is added. As a net result the river at the end of our example has a flow of Q(5), a BOD of BOD(5) and a D.O. of D.O. (3).

To continue this example let us assign values to the various flows and loads and calculate the overall effect on the stream. Remember that any load which enters the stream is a debit and any oxygen which is added is a credit.

First let us consider just flow in the River.

Assume: Q(1) Upstream flow = 200 CFS
Q(2) Municipal effluent flow = 1 CFS
Q(3) Industrial waste flow = 2 CFS
Q(4) Irrigation flow removal = 20 CFS

Now by adding the various Q values we find the flow at various points is as follows:

A = Q(1) = 200 CFS
B = Q(1) + Q(2) = 201 CFS
C = Q(1) + Q(2) + Q(3) = 203 CFS
E = Q(1) + Q(2) + Q(3) - Q(4) = 183 CFS = Q(5)

Now consider the various BOD loads and oxygen additions to the river above the irrigation withdrawal:

Assume: BOD(1) Upstream BOD = 0.5 mg/l debit
BOD(2) Municipal effluent = 100 mg/l debit
BOD(3) Industrial waste = 700 mg/l debit
DO(1) Upstream oxygen = 9 mg/l credit

Assume the waste streams contain no dissolved oxygen.

Adding algebraically, the various BOD loads and oxygen contents and multiplying by the appropriate flow values we can determine the net oxygen credit at any point as follows:

At point A the oxygen credit is:

$$\frac{Q(1)[DO(1) - BOD(1)]}{Q(1)} = \frac{200 \quad (9.0 - 0.5)}{200} = 8.5 \text{ mg/l}$$

At point B the oxygen credit is:

$$= \frac{Q(1) \ [DO(1) - BOD(1)] - Q(2)[BOD(2)]}{Q_1 + Q_2}$$

$$= \frac{200 \ (9.0 - 0.5) - 1(100)}{200 + 1} = \frac{1700 - 100}{201} = 7.96 \text{ mg/l}$$

At point C the oxygen credit is:

$$\frac{Q(1)\ [DO(1) - BOD(1)] - Q(2)[BOD(2)] - Q(3)[BOD(3)]}{Q(1) + Q(2) + Q(3)}$$

$$= \frac{200(9.0 - 0.5) - 1(100) - 2(700)}{200 + 1 + 2} = \frac{1700 - 100 - 1400}{203} = 0.98 \text{ mg/l}$$

These three calculations indicate that at a point just upstream of the irrigation withdrawal, the river has an oxygen concentration of only 0.98 mg/l. To calculate the oxygen credit at point D is unnecessary since the river will have the same concentration of oxygen as at point C. At point E the oxygen credit may be calculated as follows:

$$\frac{Q(5)[\text{Oxygen credit at D} + DO(2)]}{Q_5}$$

$$= \frac{183(0.98 + 3.0)}{183} = 3.98 \text{ mg/l}$$

Taking a look at the entire picture we see from the foregoing example that the river in its travel from point A upstream of the City to point D just behind the dam, suffered a loss of dissolved oxygen content from 9.0 mg/l down to 0.98 mg/l. This would have created a major disaster for the river since such a low oxygen content would have caused the death of nearly all desirable fish species in the impoundment behind the dam. Even the addition of quite a large amount of oxygen by the spillway turbulance in our example still only resulted in a final oxygen content of 3.98 mg/l which would not support most of the desirable fish species.

The above example illustrates only a few of the debits and credits involved in oxygen changes. There are also bank loads, bottom deposit loads, loads due to plankton changes and other biological or chemical changes too numerous and complicated to mention here. The major point to remember is that each river is a living body of water. It has organisms that live and die. These organisms eat, breathe, and produce wastes just as humans do. Their type and numbers are dependent on the cleanliness of the river. Dirty rivers will promote the growth of undesirable species which in turn will add to the overall problem.

3. **Stream Sanitation.** Stream sanitation involves the entire process of keeping as many materials as possible out of all streams. In earlier times water-borne diseases were the major problem. People were contaminating water so that downstream users were seriously affected. Removal of solids and the practice of disinfection removed most of the pathogenic organisms so that the spread of most diseases by water-borne means was checked. Today, other problems such as oxygen depletion and nutrient enrichment of waterways have become widespread. Better treatment of all wastes is the only answer to these problems.

We must constantly remember that disease organisms are still present in sewage and that we must still exercise care and vigilance to ensure removal or inactivation of these oganisms by proper waste treatment. In addition we must constantly strive to reduce all pollution loads by construction and high quality operation of our treatment works.

Sewage and industrial wastes represent only a part of the overall pollution load imposed on our rivers. They are the major present load, but they can be controlled and their effect reduced. Other loads such as from septic tank effluents, agricultural land drainage, and drainage from garbage dumps also pose a threat and these too must be brought under control. Even boating, swimming and fishing impose waste loads on rivers even though such loads may be minor. Every use decreases the quality of water. The amount of quality decrease varies, but every use represents some degree of pollution.

PUBLIC RELATIONS AND COMMUNICATION

Sewage treatment plants have long been placed in out-of-the-way places because people of the community did not want to see, smell or hear from them in any way. This trend is shifting. Communities are becoming aware that it is their responsibility to help control the entry of wastes into streams. People are using the streams more than ever for fishing, boating, swimming, water skiing and other similar uses. They expect the water to be clean and are greatly upset if it is not. New legislation, both State and Federal, has brought to light the fact that more effective pollution control is needed. The pressures that have been exerted have hit the pocketbooks of the people who have to finance sewage treatment. These factors have tended toward inquiries into what plants do and have promoted more visitations to the plants. People have become aware of the sewage treatment plant as a necessary part of the community. A bridge has been started across the credibility (reciprocal communications) gap that has existed for many years.

This new awareness has created an important job for the operator. He must practice it both on the job and off. Public relations is the total impression that is given to the public. It is the way you answer your telephone. It is the way you drive your car. There is no set pattern in deed, time or place that will define public relations. Keys to bridging the credibility gap between you and your public might be classed as control, cleanliness, courtesy, capability, communication and common sense. Publicity helps, but day to day impressions are the ones that count with your critical public.

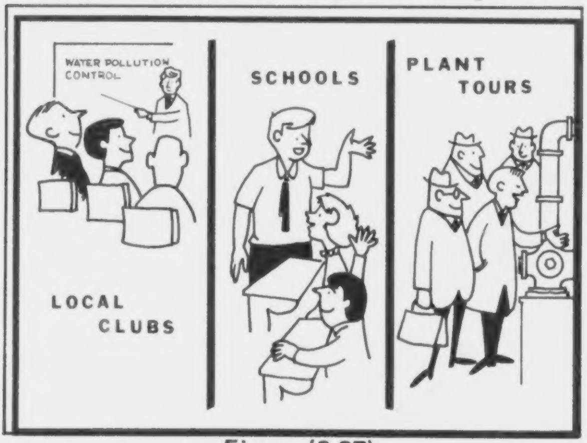


Figure (9-27)
PUBLIC RELATIONS

Let us look briefly at each of the keys of control, cleanliness, courtesy, capability, communication and common sense. Control of the plant is of vital necessity to create a day-by-day impression. The grounds, buildings and equipment must give the impression of being "shipshape" at all times. The very atmosphere of the plant should say "all is well" at any hour of the day or night. If a breakdown does occur, it should be handled with dispatch and should show that it is being controlled.

Cleanliness cannot be overemphasized. Plants are generally being designed so that they are architecturally pleasing. They are usually marked with an identification sign that says they are sewage treatment plants. We know that these plants receive wastes that nobody wants. These wastes are odorous when they are septic. It is therefore important to keep the plant as clean as possible to eliminate sources of odor. Cleanliness also extends to speech of the operator and his own personal hygiene. An operator who is wearing neat clothes and looks reasonably clean will creat an impression of "top notch" efficiency.

Every day is courtesy day, whether on the job or off. All that courtesy amounts to is following the good old-fashioned manners that were taught at home, school and church. Manners amount to treating others as you like to be treated. Politeness, sincerity, cooperation, respect and sympathetic assistance with other people's problems comprise most of the elements of courtesy. Patient listening to the problems of an irate citizen may iron out the problem and even make an ally of the citizen.

Capability in the job includes knowledge of the plant and its entire operational characteristics. This has to show up in a neat, trim plant. It shows up in the pride the operator feels in his plant. Each operator must feel that the plant he operates is his. In this way he will attain the capabilities necessary for good operation of the plant.

The fifth "C"–communication–is the most important link between the operator and his contacts. The operator has a first responsibility of getting along with his fellow operators and his administrative officers. This involves day-to-day contacts on policy, administrative and budgetary matters. It involves talking about problems and writing reports to explain what is going to happen or what has happened. Visitors are another communication link with the outside world. They often appear at just the time the plant is upset or when it is time to check the plant operation. It is still necessary to treat them courteously so that they are favorably impressed with the plant and its operation. Salesmen and service people very often show up at the most awkward moments, and the operator must take time with them to help straighten out problems. These people can be real allies, or if they are not treated properly, they can delay services to the point that it becomes difficult to run the plant. Another link in the chain of communication is with the regulatory agencies. It must be remembered that regulatory people have a job to do that is the same as that of the operator—to protect the people of the community.

The general public is of vital concern to all operators. He must be able and willing to follow up and take care of complaints with all the courtesy possible. In the same manner, it is important to work with reporters to get the best publicity that can be obtained. To get good publicity, it is important to care what people say about us. It is important to see that service and performance are properly reported. A reporter is trained to reach the public. He can be your spokesman if you give him the facts and work with him in presenting those facts to the people.

In working with reporters, the standard operating procedure for every plant should include the rule that whoever is physically present and in charge of the plant at any time is the person authorized to describe to the press what emergency conditions are (in a time of crisis) until a person of higher "rank" arrives on the scene. They aren't making atom bombs at sewage plants and to postpone reporters with a "We are not allowed to talk to reporters," may well alienate them when you might later need their enthusiastic and vigorous support for a later bond issue.

They can preface their remarks (in a time of emergency) with "the way it looks now" and then describe the situation, reminding reporters their information is **incomplete.** Situations change and reporters know this and will expect changes in developing situations.

Remember that bad news takes especially good handling. Complaint periods should have adequate coverage so that the people know what is happening. Communication is a world of talking about, writing about, listening to and understanding each other's problems.

Last, but not least, is the common sense factor of public relations. A sewage treatment plant affects other people because it does produce odors and there is identifiable debris associated with the plant. People often condemn the plant just because it is there. It would not be common sense to pretend the plant is not there. The plant is there and people should know what we are doing with it. In all dealings with people, the question must be asked, "Have I used common sense in making this decision?"

LAWS AND LEGAL PROBLEMS

1. **Introduction.** The sewage treatment plant operator is affected by laws of his city or district, the county in which the city lies, the State and the Federal government. It is of prime necessity for the operator to be familiar with the local ordinances which influence the operation of his plant. These vary from simple rules for connecting to a sewer, to complex rules for industrial wastes. In cases where counties are affected by operation or where adjacent county territories may be added to the municipal system, county laws may come into play along with the municipal ordinances. State laws have been instituted for pollution control. These laws and rules of the regulatory agencies set the standards and methods of implementing and enforcing the standards to obtain the cleanest streams that can be practicably achieved. Because most of the plants being built are financed partially by Federal funds, the pollution laws of the Federal government are enforceable on these plants. Besides these pollution control-oriented laws, each operator is affected by laws of motor vehicles, safety, retirement, trespass and others of similar nature.

2. **Local Ordinances.** It is vital to the operator to have a knowledge of local ordinances relating to the type of material that can be put into sewers and what can be done about illegal entry of waste. A good example of the problem is the chronic case of untended grease and oil traps at service stations and garages. If ordinances are not strong enough the problem can often continue and ruin the plant operation. Most municipalities or districts have fairly strict ordinances regarding the entry and strength of industrial wastes and the enforcement of these rules. These are so varied that they cannot be discussed in this manual. The municipal league of each state has copies of model ordinances and works with cities to try to get good ones in force. The main thing for the operator to think about is that he is a part of local government and should know the laws under which he operates. Some quasi-public groups develop due to alliances between municipal, county, and district governments for specific purposes. The rules of these groups also influence the operator.

3. **State Laws.** Each state has a battery of laws which directly and indirectly affect the sewage treatment plant operator. The health departments have laws relating to the protection of the welfare of people. They become vitally concerned if disease organisms are allowed to get into any water course. Pollution control laws are enforced by regulatory agencies that have the charge for keeping any deleterious material out of water courses. The laws or rules that directly affect the operator involve the following general categories:

A. Definitions of Waste.

B. Policy of the State Regarding Pollution.

C. Standards for Discharges and Streams.

D. Monitoring and Surveillance of Plants and Streams.

E. Construction Grants.

F. Annexation.

G. Permits for Discharge of Treated Wastes.

H. Enforcement of Rules by Hearings, Injunctions, or other Proceedings.

This brief outline only touches the rules under which all pollutors must live. Details are contained in the appropriate state law books and can be outlined from the state when needed.

4. **Federal Laws.** Both the Federal Water Pollution Control Administration of the Department of Interior and the U. S. Public Health Service of the Department of Health, Education and Welfare have laws relating to pollution and contamination of water. These and other Federal agencies are becoming more involved in pollution control through the grant programs which carry with them a series of rules on construction, operation and reporting. Federal laws are enforceable through proper procedures on states, local governments and industry; and it, therefore, is necessary to have some understanding of these laws, rules and regulations.

5. **Intent of Laws.** It appears when one goes through the volumes of laws that apply to pollution control that many of the laws, rules and regulations are cumbersome and hard to live with. However, it must be remembered that these laws were made by legislators duly elected by the people of their district. These legislators supposedly represent their constituents and make laws to help promote the health and welfare of their territory. Some laws, of course, are bad, but the intent is to provide rules that will make the United States a better place in which to live. If a bad law does get on the books it is up to us as citizens to help erase it.

6. **Legal Problems.** Every action that a public servant takes can lead to legal problems from a disgruntled citizen. If anything of this sort occurs to the operator of a plant, he should seek and follow the advice of the legal counsel of his municipality or district. Lawyers are trained to think in terms of legal problems and they know the procedures to follow. This is one area where self-help is a detriment.

GLOSSARY OF TERMS USED IN SEWAGE TREATMENT

The purpose of this short disucssion concerning terms used in sewage treatment has been placed here for two reasons: (1) to acquaint those who are new in sewerage work with the definition and use of certain basic language involved in the work, and (2) to assist in a better understanding of discussions and the teachings of those working in development and improvement of the field of sewage treatment. The definitions given below are not intended to be a complete glossary. For a more complete glossary reference is made to the book entitled, "Glossary of Water and Sewage Control Engineering," published under the joint sponsorships of the American Public Health Association, the American Society of Civil Engineers, the American Water Works Association, and the Federation of Sewage Works Association.

1. **General Words or Terms.**

CONTAMINATION. A general term signifying the introduction into water of microorganisms, chemicals, wastes, or sewage, which renders the water unfit for its intended use.

INDUSTRIAL WASTES. The liquid wastes from industrial processes as distinct from domestic or sanitary sewage.

POLLUTION. The addition of sewage, industrial wastes, or other harmful or objectionable material to water.

SEWAGE. Largely the water supply of a community after it has been fouled by various uses. From the standpoint of source, it may be a combination of the liquid or water-carried wastes from residences, business buildings, and institutions, together with those from industrial establishments, and with such groundwater, surface water, and storm water as may be present.

SEWAGE TREATMENT. Any artificial process to which sewage is subjected in order to remove or alter its objectionable constituents and thus to render it less offensive or dangerous.

SEWAGE TREATMENT WORKS. An arrangement of devices and structures for treating sewage, industrial wastes and sludge. Sometimes used as synonymous with sewage treatment plant.

SEWAGE WORKS. A comprehensive term which includes facilities for collecting, pumping, treating, and disposing of sewage; the sewerage system and the sewage treatment works.

SEWER. A pipe or conduit for carrying sewage and waste water.

SEWERAGE SYSTEM. A system of sewers and appurtenances for the collection of, transportation, and pumping of sewage and industrial wastes.

2. **Specific Words or Terms.**

ACTIVATION. The generation, under aerobic conditions, of zoogleal organisms capable of absorbing organic material from the sewage in the activated sludge process.

ACTIVATED SLUDGE PROCESS. A biological sewage treatment process in which a mixture of sewage and activated sludge is agitated from the treated sewage (mixed liquor) by sedimentation, and wasted or returned to the process as needed. The treated sewage overflows the weir of the settling tank in which separation from the sludge takes place.

ADSORPTION. The adherence of dissolved, colloidal or finely divided solids on the surfaces of solid bodies with which they are brought into contact.

AERATION. The bringing about of intimate contact between air and liquid by one of the following methods: Spraying the liquid in the air; bubbling air through the liquid; or by agitation of the liquid to promote surface adsorption of air.

AERO FILTER. Commercial term applied to a trickling filter containing a relatively coarse filtering material and operating at a high rate which may be maintained, if necessary, by recirculation of the filter effluent or other diluting liquids.

ALGAE. Primitive plants, one or many-celled, usually aquatic and capable of elaborating their foodstuffs by photosynthesis.

ALGICIDE. Any substance which kills algae.

ASSESSMENT. The charge against any particular parcel of land within the boundaries of an irrigation, water, sewer, drainage, or other district created for the purpose of constructing improvements, or a share of the total cost of such improvements, usually based upon the proportionate benefits received by such parcel as a result of the improvement.

AVAILABLE OXYGEN. The quantity of atmospheric oxygen dissolved in the water of a stream. It is the quantity of dissolved oxygen available for the oxidation of organic matter in sewage.

BACKSIPHONAGE. The flowing back of contaminated or polluted water from a plumbing fixture or cross connection, into a water supply line, due to a lowering of the pressure in such a line.

BACTERIA. Primitive plants, generally free of pigment, which reproduce by dividing in one, two, or three planes. They occur as single cells, groups, chains, or filaments, and do not require light for their life processes. They may be grown by special culturing out of their native habitat.

AEROBIC. Bacteria which require free oxygen for their growth.

ANAEROBIC. Bacteria which grow in the absence of free oxygen and derive oxygen from breaking down complex substances.

PARASITIC. Bacteria which thrive on other living organisms.

PATHOGENIC. Bacteria which can cause disease.

BAR RACK. A screen composed of parallel bars, either vertical or inclined, placed on a waterway to catch floating debris, and from which the screenings may be raked. Also called a rack.

BIOCHEMICAL OXYGEN DEMAND (BOD). The quantity of oxygen utilized in the biochemical oxidation of organic matter in a specified time and at a specified temperature. It is not related to the oxygen requirements in chemical combustion, being determined entirely by the availability of the material as a biological food and by the amount of oxygen utilized by the microorganisms during oxidation.

BIOCHEMICAL SEWAGE OXIDATION. The process whereby, through the agency of living organisms in the presence of oxygen, the organic matter contained in sewage is converted into a more stable or a mineral form.

BIOLOGICAL PROCESS. The process by which the life activities of bacteria and other microorganisms in the search for food, break down complex organic materials into simple, more stable substances, self-purification of sewage-polluted streams, sludge digestion, and all so-called secondary sewage treatments result from this process. Also called Biochemical Process.

BUILDING DRAIN. In plumbing, that part of the lowest horizontal piping of a drainage system which receives the discharge from soil, waste, and other drainage pipes inside the walls of the building and conveys it to the Building Sewer (House Sewer), beginning 5 feet outside the inner face of the building wall.

BUILDING SEWER. In plumbing, the extension from the building drain to the public sewer or other place of disposal. Also called the House Connection.

BURNER, WASTE GAS. A device in a sewage treatment plant for burning the waste gas from a sludge-digestion tank.

CENTRIFUGAL PUMP. A pump in which a rotating element called an impeller is used to add energy to a fluid by means of centrifugal action in order to add head to a liquid.

CHAMBER. A general term applied to a space enclosed by walls or to a compartment, often prefixed by a descriptive word, such as "Grit Chamber," "Screen Chamber," "Discharge Chamber," or "Flushing Chamber," indicating its function.

CHLORINATED LIME. A combination of slaked lime and chlorine gas (also termed as Bleaching Powder, Chloride of Lime, Hypochlorite of Lime, etc.) in which calcium oxychloride is the essential ingredient. When dissolved in water the calcium oxychloride decomposes to provide calcium hypochlorite and calcium chloride.

CHLORINATION. The application of chlorine to water, sewage, or industrial wastes, generally for the purpose of disinfection, but frequently for accomplishing other biological or chemical results.

CHLORINATION CHAMBER. A detention basin wherein chlorine is diffused through liquid.

CHLORINE. An element ordinarily existing as a greenish yellow gas about 2.5 times as heavy as air. Under atmospheric pressure and at a temperature of −30.1 degrees F. the gas becomes an amber liquid about 1.5 times as heavy as water. The chemical symbol of chlorine is Cl; its atomic weight is 35.457; and its molecular weight is 70.914.

CHLORINE DEMAND. The difference between the amount of chlorine added to water, sewage, or industrial wastes and the amount of residual chlorine remaining at the end of a specified contact period. The demand for any given water varies with the amount of chlorine applied, time of contact, and temperature.

CLOGGING, FILTER. The effect of fine particles filling the voids of the biological bed or of growths forming surface mats that retard the normal passage of liquid through the filter.

COEFFICIENT. A numerical quantity determined by experimental methods, interposed in a formula which expresses the relation between two or more variables, for the purpose of taking care of the effect of special conditions, or of correcting a theoretical relation to one as found by experiment or actual practice.

COMBINED AVAILABLE RESIDUAL CHLORINE. That portion of the total residual chlorine remaining in water, sewage, or industrial wastes at the end of a specified contact period, which will react chemically and biologically as chloramines, or organic chloramines.

COMBINED RESIDUAL CHLORINATION. The application of chlorine to water, sewage, or industrial wastes to produce directly or through the destruction of ammonia, or of certain organic nitrogenous compounds, a free available chlorine residual.

COMMINUTION. The process of screening sewage and cutting the screenings into particles sufficiently fine to pass through the screen openings.

DECOMPOSITION OF SEWAGE. The breakdown of the organic matter in sewage first through aerobic activity and then by anaerobic oxidation and nitrification.

DEGREE OF PURIFICATION. (1) A measure of the completeness of destruction or removal of objectionable impurities, such as bacteria, hardness, etc., from water by natural means (self-purification) or by treatment. (2) A measure of the removal, oxidation, or destruction of solids, organic matter, bacteria, or other specified substance affected by sewage treatment processes.

DEPRESSED SEWER. A section of sewer constructed lower than adjacent sections, to pass beneath a valley, water course, or other obstruction. It runs full or at greater than atmospheric pressure because its crown is depressed below the hydraulic grade line. See Siphon, Inverted.

DETENTION PERIOD. The theoretical time required to displace the contents of a tank or unit at a given rate of discharge (volume divided by rate of discharge).

DETRITUS CHAMBER. A detention chamber larger than a grit chamber, usually with provision for removing the sediment without interrupting the flow of liquid. A settling tank of short detention period designed primarily to remove heavy settleable solids.

DEWATERING, SCREENINGS. The removal of a large part of the water content of sewage or waste screenings by draining or by mechanical means.

DIAPHRAGM PUMP. A pump in which a flexible diaphragm, generally of rubber, is the operating part; it is fastened at the edges in a vertical cylinder; when the diaphragm is raised suction is exerted; and when it is depressed the liquid is forced through a discharge valve.

DIFFUSER. A porous plate or tube through which air is forced and divided into minute bubbles for diffusion in liquids. Commonly made of carborundum, alundum, or silica sand.

DIGESTED SLUDGE. The concentrated sewage sludge that has decomposed under controlled conditions of pH, temperature, and mixing in a digester tank.

DIGESTER COILS. A system of pipes for hot water or steam installed in a sludge-digestion tank for the purpose of heating the sludge.

DIGESTION. The anaerobic decomposition of organic matter resulting in partial gasification, liquefaction, and mineralization.

DILUTION. (1) A method of disposing of sewage, industrial waste, or sewage treatment plant effluent by discharging it into a stream or body of water. (2) The ratio of volume of flow of a stream to the total volume of sewage or sewage treatment plant effluent discharged into it.

DISPLACEMENT PUMP. A type of pump in which the water is induced to flow from the source of supply through an inlet pipe and inlet valve and into the pump chamber by a vacuum created therein by the withdrawal of some physical agency which on its return displaces a certain volume of the water contained in the chamber and forces it to flow through the discharge valves and discharge pipes.

DISSOLVED OXYGEN. Usually designated as D.O. The oxygen dissolved in sewage water or other liquid usually expressed in parts per million or percent of saturation.

DISSOLVED SOLIDS. Solids which are present in solution.

DISTRIBUTOR. A device used to apply liquid to the surface of a filter or contact bed, of two general types, fixed or movable. The fixed type may consist of perforated pipes or notched troughs, sloping boards, or sprinkler nozzles. The movable type may consist of rotating disks or rotating, reciprocating, or traveling perforated pipes or troughs applying a spray or a thin sheet of liquid.

DOSING SIPHON. A siphon for automatically discharging the liquid purposefully accumulated in a tank onto some sewage treatment device such as an Intermittent Filter or a Trickling Filter.

EASEMENT. The legal right to make use of a parcel of land for the purpose of erecting an engineering structure or for the purpose of occupying the land for a particular purpose.

EFFICIENCY. The ratio of the actual performance of a device to the theoretically perfect performance usually expressed as a percentage.

EFFLUENT. (1) A liquid which flows out of a containing space. (2) Sewage, water, or other liquid, partially or completely treated or in its natural state, as the case may be, flowing out a reservoir, basin, or treatment plant, or part thereof.

EFFLUENT WEIR. A weir at the outflow end of a sedimentation basin or other hydraulic structure.

ELUTRIATION. A process of sludge conditioning in which certain constituents are removed by successive decantations with fresh water or plant effluent, thereby reducing the demand for conditioning chemicals.

ESCHERICHIA COLI (E. COLI). A species of genus escherichia bacteria normal inhabitant of the intestine of man and all vertebrates. This species is classified among the Coliform Group.

FATS (SEWAGE). Triglyceride esters of fatty acids. Erroneously used as synonymous with Grease.

FILTER FLOODING. The filling of a trickling filter to an elevation above the top of the media by closing all outlets in order to reduce or control the nuisance of filter flies.

FILTER LOADING. (1) The liquor overlying deposited solids. (2) The liquid in a sludge-digestion tank which lies between the sludge at the bottom and the floating scum at the top.

FILTER MEDIUM. (1) Any material through which water, sewage or other liquid is passed for the purpose of purification, treatment, or conditioning. (2) Cloth used to intercept sludge solids in sludge filtration.

FILTER UNLOADING. The periodic sloughing or unloading of the film on the filter stones of a trickling filter.

FILTER VACUUM. A filter consisting of a cylindrical drum mounted on a horizontal axis, covered with filtering material made of wool, felt, cotton, etc., or by stainless steel coil springs or metal screens revolving with a partial submergence in the liquid. A vacuum is maintained under a cloth for the larger part of a revolution to extract moisture. The cake is scraped off continuously.

FLAME ARRESTER. A safety device on a gas line which allows gas, but not a flame, to pass through.

FLOATING COVER. In sewage treatment, a gas tight metal cover on a sludge-digestion tank, floating on the sludge in the digestion tank.

FOAMING SLUDGE. An increase in the gas in sludge in Imhoff and separate digestion tanks causing large quantities of froth, scum, and sludge to rise and overflow from openings or at the top of the tanks.

FREE AVAILABLE RESIDUAL CHLORINE. That portion of the total residual chlorine remaining in water, sewage, or industrial wastes at the end of a specified contact period which will react chemically and biologically as hypochlorous acid or hypochlorite ion.

FREE RESIDUAL CHLORINATION. The application of chlorine to water, sewage, or industrial wastes to produce directly or through the destruction of ammonia or of certain organic nitrogenous compounds, a free available chlorine residual.

GAUGE. A device for measuring any physical magnitude.

FLOAT. A device for measuring the elevation of the surface of a liquid, the actuation element being a buoyant float which rests upon the surface of the liquid.

INDICATOR. A gauge that shows by means of an index, pointer, dial, etc., the instantaneous value of such characteristics as depth, pressure, velocity, etc.

MERCURY. A gauge wherein pressure of a fluid is measured by the height of a column of mercury which the fluid pressure will sustain.

PRESSURE. A device for registering the pressure of solids, liquids, or gases. Use any units.

GREASE. In sewage, grease includes fats, waxes, free fatty acids, calcium and magnesium soaps, mineral oils, and other nonfatty materials. The type of solvents used for its extraction should be stated.

GREASE SKIMMER. A device for removing floating grease or scum from the surface of sewage in a tank.

GRIT. The heavy mineral matter in water or sewage, such as sand, gravel, cinders, etc.

GRIT CHAMBER. A small detention chamber or an enlargement of a sewer designed to reduce the velocity of flow of the liquid to permit the separation of mineral from organic solids by differential sedimentation.

HEAT DRIED SLUDGE. A process of drying sludge where there is an exposure of all portions of the sludge to a temperature of 700 to 800 degrees Fahrenheit for five minutes or longer.

HIGH-RATE FILTER. A trickling filter operated at a high average daily dosing rate usually between 10 mgd to 30 mgd per acre, sometimes including recirculation of effluent.

IMHOFF CONE. A conically shaped graduated glass vessel used to measure approximately the volume of settleable solids in sewage.

IMPELLER. The rotating part of a centrifugal pump containing the curved vanes.

INFILTRATION. (1) The flow or movement of water through the interstices or pores of a soil or other porous medium. (2) The quantity of groundwater which leaks into a sanitary sewer through defective joints. (3) The entrance of water from the ground into a sewer through breaks, defective joints, or porous walls. (4) The adsorption of liquid water by the soil either as it falls as precipitation or from a stream flowing over the surface.

INFLUENT. Sewage, water, or other liquid, raw or partly treated, flowing into a reservoir, basin, or treatment plant or part thereof.

INSANITARY. Contrary to sanitary principles; injurious to health.

LIFT, AIR. A device for raising liquid by injecting air in and near the bottom of a riser pipe submerged in a liquid to be raised.

LIQUEFACTION. The changing of the organic matter in sewage from an insoluble to a soluble state and effecting a reduction in its solid contents.

LIQUOR. Water, sewage, and industrial wastes or any combination of the three.

LOADING. The time rate at which material is applied to a treatment device involving length, area, or volume or other design factor.

LOW-RATE FILTER. A trickling filter designed to receive a small load of BOD per unit volume of filtering material and to have a low dosage rate per unit of surface area. (Usually 1 to 4 mgd per acre.) Also called standard rate filter.

MATTER. Solids, liquids, and gases.

INORGANIC. Chemical substances of mineral origin. They are not usually volatile with heat.

ORGANIC. Chemical substances of animal, vegetable and industrial origin. They include most carbon compounds, combustible and volatile with heat.

MINIMUM GRADE. The grade of a sewer, not under pressure, sufficient to maintain a minimum velocity when partly full which will prevent the deposition of material carried by the water.

MIXED LIQUOR. A mixture of activated sludge and sewage in the aeration tank undergoing activated sludge treatment.

MOISTURE, PERCENTAGE. The water content of sludge expressed as the ratio of the loss in weight after drying at 103 degrees Centigrade, to the original weight of the sample, multiplied by 100.

MOST PROBABLE NUMBER. In the testing of bacterial density by the dilution method, that number of organisms per unit volume which in accordance with statistical theory would be more likely than any other possible number to yield the observed test result or which would yield the observed test result with the greatest frequency. Expressed as density of organisms per 100 mls.

NIPPLE. A tubular pipe fitting usually threaded on both ends and under 12 inches in length. Pipe over 12 inches long is regarded as cut pipe.

NONDIGESTED SLUDGE. The sludge that has accumulated in a digester or septic tank but due to lack of environmental control has only partially decomposed.

OUTFALL SEWER. The outlet or structure through which sewage is finally discharged.

OVERFLOW RATE. One of the criteria for the design of settling tanks in treatment plants; expressed in gallons per day per square foot of surface area in the settling tank.

OXIDATION PROCESS. Any method of sewage treatment for the oxidation of the putrescible organic matter; the usual methods are biological filtration and the activated sludge process.

PERIPHERAL WEIR. The outlet weir in a circular settling tank, extending around the inside of its circumference and over which the effluent discharges.

PNEUMATIC EJECTOR. A device for raising sewage, sludge, or other liquid by alternately admitting such through an inward swinging check valve into the bottom of an airtight pot and then discharging it through an outward swinging check valve by admitting compressed air to the pot above the liquid.

POOLING, FILTER. The formation of pools of sewage on the surface of filter caused by clogging.

POPULATION EQUIVALENT. (1) The calculated population which would normally contribute the same amount of biochemical oxygen demand (BOD) per day. A common base is 0.167 pounds of 5-day BOD per capita per day. (2) For an industrial waste, the estimated number of people contributing sewage equal in strength to a unit volume of the waste or to some other unit involved in producing or manufacturing a particular commodity.

PROPORTIONAL WEIR. A special type of outlet weir used to control a grit chamber and maintain constant velocity with various flows. It is also used in water softening and for other purposes. The discharge through the weir is directly proportional to the head. Various types have been suggested by Sutro, Rettger, Holmes and Camp.

PUMP. A device used to increase the head on a liquid.

RAW SEWAGE SLUDGE. The accumulated suspended and settleable solids of sewage deposited in tanks or basin mixed with water to form a semiliquid mass.

RECIRCULATION. (1) The refiltration of all or a portion of the effluent in a high-rate trickling filter for the purpose of maintaining a uniform high rate through the filter. (2) The return of effluent to the incoming flow to reduce its strength.

REOXYGENATION. The replenishment of oxygen in a stream from (1) dilution water entering stream, (2) biological reoxygenation through the activities of certain oxygen-producing plants, and atmospheric reaction.

SEDIMENTATION. The process of subsidence and deposition of suspended matter carried by water, sewage, or other liquids, by gravity. It is usually accomplished by reducing the velocity of the liquid below the point where it can transport the suspended material.

SLUDGE COLLECTOR. A mechanical device for scraping the sludge on the bottom of a settling tank to a sump from which it can be drawn by a hydrostatic or mechanical action.

SLUDGE DIGESTION. A process by which organic or volatile matter in sludge is gasified, liquefied, mineralized, or converted into more stable organic matter through the activities of living organisms.

SLUDGE DRYING. The process of removing water from sludge by drainage or evaporation, through exposure to the air, application of heat, or other methods.

SLUDGE FILTER. A device in which wet sludge, usually conditioned by a coagulant, is partly dewatered by means of vacuum or pressure.

SLUDGE DEWATERING. The process of removing a part of the water in sludge by any method such as draining, evaporation, pressing, centrifuging, exhausting, passing through rollers, or acid flotation, with or without heat. It involves reducing from a liquid to a spadable condition rather than merely changing the density of the liquid (concentration) on the one hand or drying (as in a kiln) on the other.

SLUDGE SEEDING. The inoculation of undigested sewage solids with sludge that has undergone decomposition for the purpose of introducing favorable organisms thereby accelerating the initial stages of digestion.

SQUEEGEE. (1) A device, generally with a soft rubber edge, used for dislodging and removing deposited sewage solids from the walls and bottoms of sedimentation tanks. (2) The metal blades attached to the lower arms of a clarifier mechanism to move the sludge along the tank bottom.

STABLE EFFLUENT. A treated sewage which contains enough oxygen to satisfy its oxygen demand.

STANDARD METHODS. Methods of analysis of water, sewage and sludge approved by a Joint Committee by the American Public Health Association, American Water Works Association, and Federation of Sewage Works Association.

STILLING BASIN. A structure or excavation which reduces velocity or turbulence of flowing or falling water.

STORM SEWER. A sewer which carries storm water and surface water, street wash and other wash waters or drainage but excludes sewage and industrial wastes. Also called a Storm Drain.

SUPERNATANT LIQUOR. (1) The liquor overlying deposited solids. (2) The liquid in a sludge-digestion tank which lies between the sludge at the bottom and the floating scum at the top.

SUSPENDED SOLIDS. (1) The quantity of material deposited when a quantity of water, sewage, or other liquid is filtered through an asbestos mat in a Gooch Crucible. (2) Solids that either float on the surface of, or are in suspension, in water, sewage, or other liquids; and which are largely removable by laboratory filtering.

TOTAL SOLIDS. The solids in water, sewage, or other liquids; it includes the suspended solids (largely removable by filter paper) and the filterable solids (those which pass through filter paper).

TRIANGULAR WEIR. The outlet weir in a circular settling tank extending around the inside of its circumference and over which the effluent discharges.

TRICKLING FILTER. A filter consisting of an artificial bed of coarse material such as broken stone, clinkers, slate, slats, brush, over which sewage is distributed and applied in drops, films, or spray from troughs, drippers, moving distributors, or fixed nozzles, and through which it trickles to the underdrains giving opportunity for the formation of zoogleal slimes which clarify and oxidize the sewage.

UNSANITARY. Lacking sanitation; not planned to promote or safeguard health.

VOLATILE SOLIDS. The quantity of solids in water, sewage or other liquid lost on ignition of the total solids.

WATER-BORNE DISEASE. A disease caused by organisms or toxic substances which are carried by water. The most common water-borne diseases are typhoid fever, Asiatic cholera, dysentery, and other intestinal disturbances.